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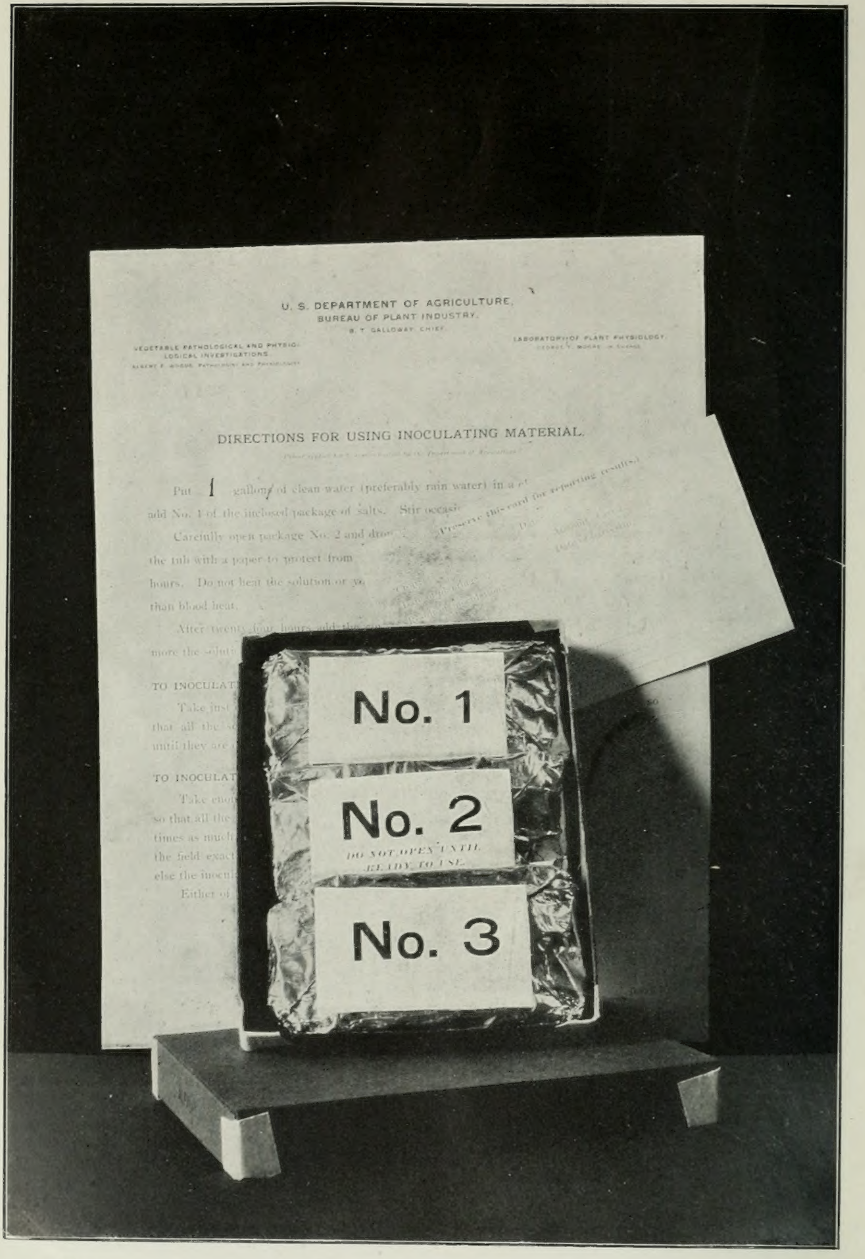

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY.
B. T. GALLOWAY, CHIEF.

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS

LABORATORY OF PLANT PHYSIOLOGY

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BUREAU OF PLANT INDUSTRY—BULLETIN NO. 71. - 80

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SOIL INOCULATION FOR LEGUMES;

WITH

REPORTS UPON THE SUCCESSFUL USE OF ARTIFICIAL CULTURES BY PRACTICAL FARMERS.

BY

GEORGE T. MOORE,
Physiologist in Charge of Laboratory of
Plant Physiology.

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL
INVESTIGATIONS.

Issued January 23, 1905. — Aug 1905

239382-91
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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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[a] Detailed to the Bureau of Forestry.
[b] Detailed to Seed and Plant Introduction and Distribution.
[c] Detailed to Botanical Investigations and Experiments.
[d] Detailed from Bureau of Chemistry.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., November 18, 1904.

Sir: I have the honor to transmit herewith a paper entitled "Soil Inoculation for Legumes; with Reports upon the Successful Use of Artificial Cultures by Practical Farmers," and to recommend that it be published as Bulletin No. 71 of the series of this Bureau. This paper was prepared by Dr. George T. Moore, Physiologist in Charge of the Laboratory of Plant Physiology, in the Office of Vegetable Pathological and Physiological Investigations, and was submitted by the Pathologist and Physiologist with a view to publication.

The subject of nitrogen fixation from the atmosphere is one of the most important problems lying at the foundation of agriculture. The great value of leguminous crops in this connection has long been well known, but until the method of distributing the proper nitrogen-fixing bacteria in pure cultures was perfected by the Department of Agriculture their value in soil improvement was not so great as it now is.

The ten half-tone plates are necessary to a clear understanding of the text.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The great importance of leguminous crops in maintaining and increasing the fertility of soils was long ago shown to be due to the nitrogen-fixing power of certain bacteria which gain entrance to and live in legume roots. It is now generally recognized that without these bacteria, legumes, like other crops, exhaust the soil of nitrogen. It is thus a matter of the greatest importance in the cultivation of these crops that the proper bacteria be present in the soil under conditions favorable for their development. The old method of inoculating soils by distributing soil from fields containing the desired bacteria is not only expensive, but there is very great danger of spreading at the same time weeds and destructive crop diseases.

Investigators in America, as well as in Europe, appreciate the great importance of securing nitrogen-fixing bacteria in pure cultures for distribution. We had great hope that Doctor Nobbe's nitragin would meet the requirements. These cultures were tested very carefully in this country and in Europe, but were found to be unsatisfactory. We still hoped, however, that the method could be perfected. Mr. W. T. Swingle was therefore instructed to proceed to Europe and confer with Doctor Nobbe regarding the future prospects of his method of pure-culture distribution. Finding that the outlook was rather unsatisfactory, upon Mr. Swingle's return we decided to undertake a thorough investigation of the legume and other nitrogen-fixing organisms, with a view to increasing their agricultural value. The plan was carefully considered and approved by the Chief of the Bureau, the Secretary of Agriculture, and by Congress, and the necessary funds were provided. Finally, we succeeded in securing the services of Dr. George T. Moore to undertake this investigation. With the able assistance of Messrs. Kellerman, Robinson, and Goll, he has succeeded in perfecting the pure-culture method of distribution even beyond our expectations.

Doctor Moore in the course of the investigations soon discovered why it was that the former methods of culture and distribution were so uncertain in their results. He worked out improved methods of making the cultures and increasing by growth in non-nitrogenous media the nitrogen-fixing power of the organisms, and perfected a method of drying them by which their activity can be preserved indefinitely. These processes have been patented by the Department in the name of Doctor Moore for the purpose of protecting them for the use of the general public.

It is now possible as a result of this work to inoculate at very small expense the seed of all leguminous plants which it may be desirable to cultivate. Bacteria for various legumes were distributed during the past year to a very large number of applicants scattered in nearly every section of this country and in many foreign countries. The results obtained have, as a whole, been extremely satisfactory. The report submitted herewith presents the results of the work up to the present time.

While investigation in connection with legumes is at present the most important phase of the work, careful attention is also being given to nitrogen-fixing bacteria which occur in connection with other plants, and especially those forms which live independently of special plants.

The facts presented in this report demonstrate the great practical value of thorough and accurate scientific investigation of the problems lying at the foundation of agriculture.

ALBERT F. WOODS,
Pathologist and Physiologist.

OFFICE OF VEGETABLE PATHOLOGICAL
AND PHYSIOLOGICAL INVESTIGATIONS,
Washington, D. C., November 17, 1904.

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SOIL INOCULATION FOR LEGUMES;

WITH REPORTS UPON THE SUCCESSFUL USE OF ARTIFICIAL CULTURES BY PRACTICAL FARMERS.

INTRODUCTION.

The primary object in undertaking an investigation of the fixation of nitrogen by the root nodules of legumes was to devise, if possible, some method of bringing about the artificial introduction of the necessary organisms into a soil which was naturally devoid of them, and at the same time to attempt, as far as possible, to correlate and reconcile the vast amount of conflicting evidence that has been accumulated by various investigators in regard to the exact nature of the organism, where the nitrogen is fixed, the effect upon the host, and similar problems.

It will not be possible in an article of this kind to give more than a brief historical sketch of the work that has been done by previous investigators, but in view of the satisfactory review of the literature up to 1892 by Atkinson[a] and by Jacobitz[b] in 1901 an exhaustive consideration of the subject in this way hardly seems necessary.

THE FIXATION OF FREE NITROGEN.

Ever since anything has been known in regard to plant nutrition and the necessary part that various gases and minerals play in the successful growing of crops, scientific men have realized the tremendous importance of conserving the world's store of nitrogen, and have made every effort either to husband or to increase all available sources of supply. In the early days, when it was first being realized that nitrogen was so essential to plant life—in fact, was at the very foundation of agriculture—no particular alarm was felt. Botanists had demonstrated that plants obtained their carbon from the carbon dioxid of the air, and since this gas is present in so much less quantity than nitrogen it was believed that by no possible means could the most essential of plant foods be exhausted. However, when it was shown that plants were unable to use free nitrogen and must obtain it directly from the soil in a highly organized form, the importance of the problem increased greatly, and the gravest consequences were predicted by those familiar with the rapidity with which this valuable element was being wasted. But a short time ago Sir William Crookes[a] predicted that within thirty or forty years England would experience a wheat famine, due to the exhaustion of nitrogen in the soil, that would be appalling in its effect: and Prof. Bela Korasey's warnings to Hungary have been even more emphatic. Indeed, Liebig, more than fifty years ago, in speaking of one of the most common methods of destroying sources of available nitrogen, said:

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[a] Bot. Gaz., xviii, pp. 157, 226, 257. 1893.

[b] Centralbl. für Bakt., Par. u. Infec., II Abt., VII. November, 1901.

> Nothing will more certainly consummate the ruin of England than the scarcity of fertilizers. It means the scarcity of food. It is impossible that such a sinful violation of the divine laws of nature should forever remain unpunished, and the time will probably come for England, sooner than for any other country, when, with all her wealth in gold, iron, and coal, she will be unable to buy the one-thousandth part of the food which she has during hundreds of years thrown recklessly away.

The ways by which combined nitrogen is rendered unavailable for plant food are well known and need no elaborate discussion. The constant cropping of land, combined with our modern sewage system, which prevents the return to the soil of such a large and legitimate nitrogen supply, are sufficient to indicate the extent of this loss without considering the destruction of nitrogenous compounds by the denitrifying bacteria, the burning or exploding of nitrate of soda, and the leaching out of this and other salts which would otherwise be most valuable as fertilizers. These things would not merit so much consideration were it not for the fact that, unfortunately, the world's supply of two of the richest sources of nitrogen—guano and saltpeter—is being exhausted rapidly. Guano has already ceased to be of any great importance, and while it is difficult to obtain precise estimates as to the available amount of saltpeter, it is very certain that at the present rate of its consumption (estimated at 1 billion tons per year) it can not last for a very great length of time, some placing the limit at less than fifty years. It should also be remembered that the natural product, while so rich in nitrogen, is also so expensive that for the general farmer the cost is almost prohibitive. The same may be said of the process recently proposed for the manufacture of nitrogen salts by means of electricity. While the discovery and perfection of such a method is calculated to calm the fears of those who predict a nitrogen famine, it is not one that appeals very strongly to the farmer so long as the price remains where it is.

Regardless of these facts, there are many well-informed men, both at home and abroad, who have always maintained that the possibility of anything approaching a nitrogen famine is so remote as to be unworthy of consideration. In order that this view may be substantiated, it will be necessary to examine into the conditions existing in nature which permit of the restoring of gaseous nitrogen to a combined form.

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[a] Brit. Assoc. Ad. Sci., Bristol, 1898. Presidential Address.

One of the sources which was formerly supposed to be of considerable importance in returning nitrogen to the earth was by means of the ammonia compounds of nitrous and nitric acid which are present in the air and are often carried into the soil by rainfall. This need not be considered, however, it having been shown that the amount of potassium or sodium nitrate per acre brought into the soil by the rain is, with the exception of a few places in the Tropics, almost infinitesimal, being less than 1 pound per year.

That electricity has some part in fixing nitrogen in a form suitable for plant food has been understood for a considerable length of time. Lightning discharges fix in the soil nitrogen from the air, and a small percentage of this element becomes available in this way. The theory has even been advanced by M. Berthelot that plants in high altitudes will produce good crops without the use of any artificial fertilizer, owing to the greater tension of electricity in these regions, the influence of electric waves permitting the plants to absorb nitrogen in a way that plants not so influenced are unable to do. It certainly seems true that plants elevated to a considerable height will absorb more nitrogen than those at a lower level, but whether this is due to a direct influence of electricity upon the plant itself is perhaps a question.

It has likewise been a matter of common observation that some land allowed to lie fallow frequently increases in its supply of available nitrogen, and to an extent much too great to have been fixed merely by lightning or electrical action of any kind. Consequently, the discovery by Schloesing and Müntz[a] in 1877 that the formation of nitrites from the organic products of animal and vegetable life was produced by living organisms, and the isolation of these bacteria by Jordan and Richards[b] in our own country, as well as by Winogradsky,[c] Frankland,[d] and Warington[e] abroad, were expected to throw much light upon this hitherto little understood subject. Nothing of any practical importance, however, was attempted until after 1891, when Schloesing and Laurent showed that certain organisms had the power of fixing nitrogen in the soil directly from the atmosphere. Experiments were then undertaken along this line, and results obtained which demonstrated that there are unquestionably in the earth a few organisms, probably both bacteria and algæ, which can directly fix free nitrogen without the aid or interposition of any other plant. Kruger and Schneiderwind[a] have given the result of a test with a bacterium which was able to fix 0.0046 of a gram of nitrogen in 100 cubic centimeters, and numerous other results are recorded showing the beneficial effect of certain organisms of this class upon all crops. Since in many cases the bacteria increased the nitrogen content of the soil so decidedly, it seemed worth while to attempt to bring about an artificial introduction of the peculiar bacteria involved. Before long a patented product, known as alinit, was placed on the market, and numerous trials designed to demonstrate its efficiency were made, but with such indifferent success that the product was withdrawn from sale. Up to the present, therefore, it can safely be said that nothing has been accomplished which would lead to the extensive use of such a process for enriching the land, although the possibility of eventually securing the proper organism and method for distributing it is not unlikely.

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[a] Compt. Rend., Paris, 84: 301.

[b] Mass. State Board of Health Rept., 1890, pp. 865–881.

[c] Ann. de l'Inst. Pasteur, 1890, p. 23.

[d] Phil. Trans. Roy. Soc., London, 1890, B., 107.

[e] Trans. Chem. Soc., 1891, p. 502.

BENEFICIAL EFFECT OF LEGUMINOUS CROPS.

From the earliest days of agriculture it has been recognized that all plants belonging to the Leguminosæ had a decidedly beneficial effect upon the soil. Pliny wrote, "The bean ranks first among the legumes. It fertilizes the ground in which it has been sown as well as any manure," and again, "The lupine enriches the soil of a field or vineyard as well as the very best manure. The vetch, too, enriches the soil and requires no attention in its culture." Varro, in De Re Rustica, I, 23, writes, "Legumes should be sown in light soils; indeed, they are planted not so much for their own crop as for the following crop, since when they are cut and kept upon the ground they make the soil better. Thus the lupine is wont to serve as a manure where the soil is rather thin and poor." There are also in ancient writings many other references to the importance and necessity of including some leguminous crop in the regular rotation. Naturally the explanations offered to account for this beneficial effect were various, perhaps the most universal belief being that the root system of these plants was much more extensive than that of grains and root crops and consequently brought up plant food from considerable depths, which not only served the legume, but was likewise available for subsequent crops. Thaer[b] in 1809 advanced the theory that the cultivation of leguminous crops might improve the soil by taking up nutriment from the air and depositing it in the soil through the roots and stubble; but this was merely a conjecture without any experimental basis. Still later, John[a] demonstrated that there was not only an increase in humus after a leguminous crop, but also a definite increase in nitrogen. He was unable, however, to suggest any explanation. In 1854, Boussingault[b] promulgated his classic experiments demonstrating the fact that plants could not assimilate free nitrogen gas. His work was substantiated by the joint labors of Gilbert, Lawes, and Pugh,[c] and although Ville[d] and others still maintained the fallacy of the investigations, it soon became as well established as any fact in plant physiology that the only efficient source of nitrogen supply was in the fixed forms supplied through the roots.

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[a] Landwirthsch. Jahrb., 19, Heft 4-5, 1900, pp. 801-804.

[b] Rationelle Landwirthsch., 1 Aufl., Bd. 1, 1809.

By this time it was beginning to be more generally known that the Leguminosæ were capable of growing in soil practically devoid of nitrogen, and consequently great difficulty was experienced in reconciling what certainly appeared to be two contradictory statements. So well established, however, was the work of Boussingault and others that no very great doubt was cast upon the question of how plants obtained their nitrogen, and an attempt was made to explain the difference through some inherent peculiarity of the legumes themselves. After a series of suppositions, all of which were incorrect, Helriegel[e] announced at a scientific meeting in 1886 that the source of nitrogen for these plants was unquestionably the atmosphere, and two years later, together with Willfarth,[f] he demonstrated the fact that the growth of plants in soil free from nitrogen always occurred after the development of nodules or swellings upon the roots. Later the results of these two men were fully substantiated by many other investigators, and the explanation of the long unsolved problem was made possible. The statement is made by Doctor Young[g] that while the discovery of the fact that the nodules of the legumes enabled them to fix "free nitrogen" is usually ascribed to Helriegel, in reality "Messrs. Hunter and McAlpine were teaching the same fact to their students years before." Attempts to verify this statement have been unsuccessful.

Although Helriegel and Willfarth were probably the first to connect definitely the function of nitrogen fixation with the root nodules, they were not by any means the first who had noticed these structures or had attempted to ascribe some function to them. Malpighi,[h] in 1687, gives a description of what he calls the gall formations of the legumes, and in the early part of the last century Karl von Wulffen[a] described the "tiny tubercles" which occur only on legumes, and recommended the cultivation of the white lupine for the improvement of sandy soil. Persoon and Fries, according to Prazmowski,[b] considered the growths to be peculiar fungi related to Sclerotium, and De Candolle[c] believed them to be lenticels. By both Trevisanus[d] and Kolaczek[e] they were regarded as normal plant structures, the first maintaining that they were undeveloped buds with a tubercular formation, while the latter called them "sponge roots," and believed that they served in absorption. The first complete work which gave the detail of the structure of the swellings on legumes was Woronin,[f] who, in 1866, very satisfactorily described them, and, furthermore, for the first time propounded the theory that they were caused by vibrio-like organisms which he discovered within the nodule. From this time up to the date of Helriegel's definite announcement, there were numerous investigators who attempted to solve the problem, but without hitting upon its solution. As late as 1887 Gasparini[g] considered them merely malformed and swollen lateral roots, and the most of those concerned with the question seemed to agree with the view put forward by Eriksson,[h] that the swellings were a purely diseased condition produced by some fungus.

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[a] Kuhn's Ber. a. d. Lab. d. Landwirthsch. Inst. Halle, 1895, p. 111.

[b] Mem. de Chim. Agric. et de Physiol., Paris, 1854.

[c] Phil. Trans. Roy. Soc., London, 1861.

[d] Compt. Rend., Paris, xxxv, 1852; xxxviii, 1854; xli, 1855.

[e] Tagebl. der 59 Versamml. Deutsch. Naturforscher u. Aerzte in Berlin, 1886.

[f] Verlagsheft zu der Zeitschr. des Vereins für Rübenzuckerindustrie des Deutschen Reichs, Berlin, 1888.

[g] Nineteenth Century, 46, 1899, pp. 782–791.

[h] Opera Omnia, Anatom. Plantar., 1687, Pars Secunda.

While at first the observations of Helriegel and Willfarth were by no means universally accepted by botanists, the numerous verifications of their work by Lawes and Gilbert,[i] Atwater and Woods,[j] Ward,[k] Kossowitsch,[l] Wagner,[m] and many others soon left no other explanation possible, and it became practically an accepted fact that all legumes were beneficial to the soil because of the presence of peculiar swellings upon their roots which enabled the plants in some way to acquire nitrogen from the air. On the other hand, the nature of the organism which produced the tubercle was not readily decided, and even up to the present time there is considerable discussion as to its character and systematic position.

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[a] Ueber den Anbau der Weissen Lupine im Nördlichen Deutschland, Madgeburg, 1828.

[b] Landwirthsch. Versuchstat., 37: 169.

[c] Prodromus, II, 1825. Also, Mem. sur la Famille des Legumineuses, 1825.

[d] Bot. Zeitschr., 1853.

[e] Lehrbuch der Botanik, 1856.

[f] Mém. de l'Académie Imp. des Sciences de St. Petersburg, Ser. VII, X, No. 6, 1866.

[g] Ber. der Deutsch. Bot. Gesellsch., 1887.

[h] Acta, Univ. Lund., 1874.

[i] Phil. Trans. Roy. Soc., London, clxxx, B., 1—107.

[j] Amer. Chem. Jour., xiii, 1891.

[k] Phil. Trans. Roy. Soc., London, vol. 178, 1887.

[l] Bot. Zeit., 1892.

[m] Deutsch. Landwirthsch. Presse, 1893.

In addition to the ideas already referred to that the nodules were galls, the result of insect or worm bites, and that they were due to pathogenic fungi, the view was advanced by Brunchorst[a] that the fungus-like strands and the bacteria-like bodies had no connection whatever, the first being of true fungus nature, while the latter were manufactured directly by the plant and after fulfilling an unknown purpose were reabsorbed. This author suggested the name *bacteroids* for the branched and rodlike forms discovered by Woronin, and maintained that the root tubercles were normal structures formed for the purpose of absorbing these when their function was complete. Frank,[b] who had previously advanced other views on the subject, at once accepted the statement of Brunchorst, his former pupil, but went a step further and maintained that even the fungus-like strands were products of the legume cell, and that the whole nodule was merely an organ for absorbing nitrogenous substances from the soil. Schindler[c] likewise coincided with most of these views, and Tschirsch[d] elaborated the point in regard to the origin of the strands and "bacteroids" to the fullest extent.

Enough has been given to show the great diversity of opinion among the leading authorities with regard to both the cause and result of the root nodules of legumes. A great many other observations might be referred to, but they would add so materially to the length of this bulletin and to so little purpose that it seems best not to consider them. The more important investigations necessary for a proper understanding of the present-day opinions will be referred to at the particular point to which they especially apply.

DIRECT EFFECT OF NODULES UPON LEGUMES.

The actual benefit of the presence of root nodules upon various leguminous plants has been so thoroughly demonstrated by numerous observers, both in this country and abroad, that it hardly needs further proof at this time. As has already been referred to, the early work of Helriegel and Willfarth, together with that of Lawes and Gilbert and of Warington in England, and of Atwater and Woods in this country, was quite sufficient to demonstrate the close connection between the fixation of nitrogen in some way by the plant and the presence of the tuber-like swellings on its roots, and there are few, if any, who would maintain that this peculiar function is not, under most circumstances, distinctly beneficial.

The direct effect of the nodule-forming bacteria upon legumes may be demonstrated either by means of greenhouse experiments conducted under controlled conditions or by observations upon distinct groups of plants in the field, one lot grown in contact with the bacteria, the other without. Atwater and Woods[a] were the first investigators to show that legumes planted in quartz sand from which all nitrogenous matter had been burned and watered with a nutrient solution devoid of nitrogen in any fixed form would flourish and produce a normal growth when root nodules were present, but would perish as readily as wheat or corn, or similar plants when deprived of the proper bacteria. This experiment has been repeated since by numerous investigators, with various modifications, until it is universally believed that the presence of the bacteria is of the utmost importance and necessity to the legume when growing in a soil containing little or no nitrogen. Indeed, it is possible to demonstrate that a legume growing in a poor sandy soil provided with nodule-forming bacteria will be even more vigorous and produce a better crop than plants growing in moderately rich soil devoid of the bacteria. This fact is well illustrated by the following experiment: Three pots of sand from which all nitrogen had been burned were planted with yellow vetch seed and treated in the following manner: Pot No. 1 was inoculated with nitrogen-fixing organisms and watered with a nutrient solution devoid of nitrogen. Pot No. 2 was not inoculated, but was watered with the same nitrogen-free solution. Pot No. 3 was likewise uninoculated but was supplied with a liberal amount of nitrogen in the form of potassium nitrate. The results were as follows: Pot No. 1, which was inoculated, grew plants averaging 6.16 grams in weight. Pot No. 2, which had no nitrogen provided, showed the poorest growth, average plants but 0.33 gram in weight, while pot No. 3, which was well fertilized, produced plants weighing but 2.65 grams. That is to say, in this particular instance, the inoculated vetch exceeded the uninoculated but fertilized vetch nearly three times in weight, while plants receiving no nitrogen were nearly twenty times smaller than those having nodules. Similar results have been obtained in the field.

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[a] Ber. der Deutsch. Bot. Gesellsch., III, 1885.

[b] Deutsch. Landwirthsch. Presse, 1886.

[c] Journ. für Landwirthsch., xxxiii, 1885.

[d] Ber. der Deutsch. Bot. Gesellsch., VII, 1887.

Rev. William Brayshaw, of Grayton, Md., reports that he "sowed two lots of seed side by side, one inoculated, the other with 100 pounds of South Carolina rock. Inoculated made double the growth and bade fair to give three times the quantity of hay."

With peas, S. N. Lowry, of Philadelphia, found that "inoculated vines yielded once and a half the crop yielded from ground not inoculated, but which was manured," and Jeremiah Gardner, of Gaffney, S. C., writes, "My peas were better than the peas of others who used commercial fertilizer. They ripened early and evenly. I consider inoculation a boon to agriculture."

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[a] Conn. Storrs Ag. Exp. Sta. Rept., 1889, p. 211; and 1890, p. 312.

H. D. Rixley, of Utica, N. Y., reported that inoculation of five acres of peas was in "every way satisfactory. Got as large a yield per acre as on five acres in same field with heavy barnyard fertilization."

With Canada field peas G. L. Thomas, near Auburn, Me., was able to secure about the same yield with inoculation that he obtained upon similar land after the addition of 800 pounds of fertilizer and 1 ton of barnyard manure, at less than one-half the cost.

One of the first as well as the most satisfactory demonstrations of the beneficial effect of the presence of nodule-forming bacteria upon leguminous crops was made by Prof. J. F. Duggar[a] at the Alabama Experiment Station in 1896 and 1897. In one field where hairy vetch had not been grown previously and the fertilizer used contained phosphoric acid and potash without any nitrogen, the yield was but 235 pounds of hay per acre. On a similar plot, treated in a similar manner, with the exception of the addition of some soil from an old field containing the proper bacteria, the yield of hay was 2,540 pounds, or an increase of over 1,000 per cent. Similar experiments with field peas, clover, and other legumes showed an increase of from 50 to 300 per cent in those plants bearing tubercles as compared with those not possessing them.

In addition to these pioneer experiments of Duggar, there have been numerous other investigators in this country who have obtained similar results. The experiment stations in Mississippi, Kentucky, Kansas, and elsewhere have almost without exception demonstrated most strikingly the immediate advantage of the presence of nodules in all leguminous crops.

Perhaps one of the most satisfactory demonstrations of the ability of legumes to put nitrogen into the soil was the one carried on at the Rothamsted Experiment Station[b] in England for a number of years. Indeed, the great value of the experiments consists in the comparatively long period of time which they cover, thus permitting a thorough comparison of results and a more perfect elimination of external factors. In a series including white clover, vetches, lucern, and other legumes, begun in 1878 and continued for twenty years, it was found that in the first 27 inches of soil the ten sets of samples taken from leguminous plots averaged 6,604 pounds of total nitrogen per acre, while the three sets of wheat soils averaged but 5,847 pounds, showing an average gain of 757 pounds of nitrogen per acre under the influence of leguminous vegetation. It should also be borne in mind that the annual output of nitrogen in the crops from leguminous land was very much greater than from the other plots, in most cases being more than twice the amount of nitrogen per acre. Where an acre of wheat and fallow lands yielded only 12 pounds of nitrogen per annum, white clover produced 24 pounds, so that in addition to the actual accumulation of nitrogen in the soil there is a tremendous output of organic nitrogen in the crops, which has been fixed from the atmosphere, a large part of which will become available if the crop is turned back into the soil as a green manure.

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[a] Ala. Exp. Sta. Bul. 76, 1897.

[b] U. S. Dept. Agr., Of. Exp. Sta. Bul. 8, 1892.

EFFECT OF NODULE-BEARING LEGUMES UPON SUCCEEDING CROPS.

Another graphic way of showing the effect of a leguminous crop possessing nitrogen-fixing nodules upon a soil is to note the vast differences between crops of grain or vegetables that follow legumes and a similar crop grown on fallow land or following a grass or vegetable crop. In addition to the experience of every scientific farmer, which, of course, has given rise to the very common practice of including some legume in rotation, the results of trials by nearly every experiment station in the United States have shown time and again the importance and even necessity of sowing the land to some leguminous crop at the end of a definite period. It is easily proved that part of this benefit is due to the additional amount of nitrogen fixed by the root nodule and not to the unusual length of the root system or other peculiarities of the plant.

J. F. Hickman[a] showed that wheat sown on very poor clay land where *Melilotus alba* had been grown for three years yielded 26.9 bushels per acre, while the same variety on adjoining land which had been in corn and oats produced but 18.6 bushels.

F. E. Emery[b] gives a record of the yields in three and four years from plots on which wheat had been grown continuously. The land upon which a crop of cowpeas was grown every summer increased the yield of grain in 1891 by an average of 13.78 bushels per acre, and in 1892 by 15.6 bushels. In addition, the use of cowpeas as a manure resulted in nearly doubling the number of stalks per stool and increased the height of the plants by nearly 9 inches and the length of the heads by 5⅔ inches.

F. E. Gardner, and Davenport and Fraser, in the Illinois Experiment Station Bulletins Nos. 37 and 42, show that corn grown in rotation with oats and clover yields 40 per cent more than corn in continuous culture.

A. T. Neale[c] demonstrates that one dollar invested in clover seed returns four times as much as one dollar invested in nitrate of soda. Four acres dressed with pea vines yielded 93 bushels of rye; four acres of timothy sod yielded 18 bushels of rye. Thus, green manure with peas increased the rye crop more than fivefold.

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[a] Ohio Exp. Sta. Bul. 42.

[b] N. C. Exp. Sta. Bul. 91.

[c] Del. Exp. Sta. Rept., 1892.

J. F. Duggar[a] found that oats grown after cowpeas, the vines having been plowed under, produced 10.4 bushels of grain and 229 pounds of straw per acre more than oats grown after German millet plowed under as fertilizer. The average yield of oats per acre after velvet beans was 33.6 bushels, after cowpeas 31.6 bushels, and 8.4 bushels after crab-grass and weeds and German millet.

R. H. Miller and S. H. Brinkley[b] have shown that when crimson clover was plowed under as a manure early in May the yield of potatoes was increased by more than 19 bushels per acre the first year and 34.4 bushels the second year, or more than 50 per cent.

G. B. Irby,[c] in experimenting to determine the value of cowpeas to succeeding crops of cotton, found that fields where no fertilizer was used, but which had been sown to cowpeas, gave a difference of 372 pounds of seed cotton per acre over those where fertilizers had been added.

On the other hand, some experiments with soy beans at the Massachusetts Experiment Station[d] would seem to indicate that legumes do not always have a beneficial effect upon the succeeding crop. W. P. Brooks and H. M. Thompson,[e] in the Massachusetts Hatch Experiment Station Report for 1899, recorded such results. Goesmann[f] some seven years earlier had had the same experience with this crop, finding that the increase in yield was, in general, proportionate to the amount of nitrogen which he had added as fertilizer. In 1896, Goesmann's[g] results showed "that there was not the least evidence of any ability on the part of the soy bean, when grown before a grain crop and harvested, to make nitrogen manuring of the grain crop unnecessary."

The examples demonstrating the great benefit which a leguminous crop has upon the succeeding crop might be extended indefinitely, but enough have been given to prove that it is the almost universal belief, as the result of definite experiments, that a leguminous crop is equal to a considerable amount of nitrogenous fertilizer, and that the crop which follows the legume is benefited to a marked degree. In Germany the number of pounds per acre of nitrogen added to the soil by legumes is estimated at 200 pounds. In the United States the average from sixteen States is 122 pounds. When it is remembered that a high grade of nitrate of soda contains but about 15 per cent of nitrogen, while much that is on the market contains considerably less, it will be seen that a crop of legumes is equal to from 800 to 1,000 pounds of nitrate of soda per acre, which at the present rate for this fertilizer is equal in value to from $20 to $25.

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[a] Ala. Exp. Sta. Bul. 105, 1899.

[b] Md. Exp. Sta. Buls. 31, p. 75, and 38, p. 58.

[c] Ark. Exp. Sta. Bul. 46, 1897, p. 86.

[d] Mass. Hatch. Exp. Sta. Rept., 1899, p. 37.

[e] Ibid., 1899, p. 32.

[f] Ibid., 1892, p. 170.

[g] Ibid., 1896, p. 171.

ARTIFICIAL INOCULATION OF THE SOIL.

Since the desirability of introducing a leguminous crop into rotation seems to be of such importance, and the benefits to be obtained from a nodule-bearing plant are so evident, it is natural that every effort has been made to obtain crops which possess the power of using atmospheric nitrogen. It has been found, however, that although in a great many instances the organisms producing nodules are naturally abundant in the soil and the mere planting of the legume seed is sufficient to produce a crop capable of fixing nitrogen, there are also some localities which are devoid of the necessary bacteria, and in such places the leguminous crop is of no more benefit to the soil than corn or wheat, or other crops whose yield might be a greater source of revenue.

SOIL TRANSFER.

It therefore has become necessary to devise some means of artificially introducing into the soil the nodule-producing bacteria, and naturally the simplest means of accomplishing this has been to transfer earth known to contain the proper organisms and capable of producing nodules to the fields where it was desirable to introduce such bacteria. This soil-inoculation method is one which has been practiced widely, both in this country and abroad, oftentimes with the best results, but not with universal success. Reports have been received from various places stating that even where soil known to contain the proper germs was used the results were not satisfactory. That this failure was not due to the character of the soil or other adverse conditions is proved by the success of other methods of inoculation upon the same kind of land at the same time. The large amount of earth necessary to produce thorough inoculation often makes it a laborious and expensive process when the fields to be treated are at a considerable distance. In addition to the expense and labor involved, however, there is a more serious objection because of the possibility of transferring plant diseases from one field to another.

H. C. Coesten, of Walnut, Kans., reports having transplanted the "leaf-blight" to his field by this method, and many instances are known in the South of the wilt of cowpeas being disseminated by carrying soil from one field to another. There can be no doubt that certain diseases of plants, the spores of which remain in the earth, are widely disseminated by such a means of attempting to produce inoculation by the transfer of soil; and where the disease is one which causes great damage to leguminous crops and is readily transported, it has become necessary to abandon inoculation altogether. There is also great danger of introducing objectionable weeds wherever soil from one locality is introduced into another region. Even though the weeds may not have been serious in the first field, the great numbers of dormant seeds which often require but the slightest change in environment to produce germination are always a menace, and a number of instances have been reported to the Department where the desired leguminous crop was completely choked out by the introduced weed. The director of the Mississippi Experiment Station writes: "Owing to the fact that our alfalfa fields are more or less full of Johnson grass, we are unable to send soil for the purpose of inoculation without distributing this objectionable grass to sections where the farmers are trying to keep it out."

NITRAGIN.

In order to escape the difficulties previously mentioned, Nobbe conceived the idea of bringing about inoculation by means of pure cultures. This was to be accomplished by isolating from the nodule by means of a gelatin plate the right organisms and then transferring to tubes or bottles containing nutrient agar. To this culture of nodule-forming bacteria was given the trade name of "nitragin." Seventeen different kinds of nitragin were prepared from the nodules of as many different plants, and arrangements were made to have them put up on a large scale and placed upon the market by a well-known firm of manufacturing chemists. Experiments with nitragin in Germany met with varying degrees of success. In some instances its use seemed to produce an abundant formation of nodules, while in other cases no benefit could be obtained. In this country the results obtained by Duggar were very satisfactory, but certain other investigators were not able to secure inoculation.

W. M. Munson,[a] while having fair success with soy beans, failed to get any satisfactory results with clovers, peas, vetches, and other legumes, and his results did not warrant the recommendation of the use of nitragin for a leguminous crop.

W. P. Brooks[b] tried nitragin on crimson clover, alfalfa, and common red clover without appreciable effect. B. D. Halstead[c] experimented with a number of legumes and tried three different kinds of nitragin, and as a result there was no evidence that nitragin was of any value in the formation of nodules.

More recently, Maria Dawson,[d] in a series of experiments extending over three consecutive years, concluded that on peat, clay, loam, or ordinary garden soil the inoculation with nitragin proved to be both useless and superfluous.

In spite of these failures, however, a large number of citations might be given which indicate that under certain favorable conditions nitragin was successful in producing nodules upon leguminous crops. The chief difficulties seem to have been in securing cultures of the proper degree of virulence and in preventing deterioration because of being subjected to too much heat or varying degrees of moisture. The age of the culture was also of importance, the manufacturers limiting the time of efficiency to about six weeks. Owing probably to inability to maintain the efficiency of the culture to its highest degree, and the adverse conditions to which it was often subjected during transportation, the percentage of failures in the use of nitragin was so great that its manufacture was given up, and it is no longer for sale under that name. Consequently, even though this preparation had been found to be satisfactory in Europe, the necessity for devising some method of producing nitrogen-fixing nodules free from the objectionable features of transferring soil remained the same. For this reason the Laboratory of Plant Physiology of the Department of Agriculture undertook a scientific investigation of the root-nodule organism, and as a result it is believed that a thoroughly practical and satisfactory method of bringing about artificial inoculation has been devised.

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[a] Maine Exp. Sta. Repts., 1897, p. 144, and 1898, p. 208.

[b] Mass. Hatch Exp. Sta. Rept., 1897, p. 26.

[c] N. J. Exp. Sta. Rept., 1899, p. 375.

[d] Ann. Bot., **15**: 511–519, 1901.

NATURE OF THE ORGANISM.

Before any improvement could be hoped to be made upon methods already in use for bringing about artificial inoculation it was necessary to become thoroughly acquainted with the precise nature of the nodule-forming organism, for, in spite of the fact that these organisms occur in great quantities and that the interior of the nodule constitutes what is practically a pure culture, there has been the widest difference of opinion as to the morphology and life history of these bodies. Beyerinck[a] was the first to cultivate the bacteria successfully, although a year previous Marshall Ward[b] had, by a series of careful experiments, established the fact that the nodule was due to some fungus-like organism present in the soil, and as early as 1886 Woronin[c] expressed a belief that the cause of these abnormal growths was due to foreign organisms, possibly the "vibrio-like bodies" which he was the first to discover and describe.

One reason for the different theories in regard to the true cause of the legume nodule has undoubtedly been on account of the various and diverse forms assumed by the organisms found in the nodule at different times and under different conditions. An examination of a mature nodule of almost any legume will show large numbers of rod-shaped bacteria as well as the characteristic branched forms, but it is probable that in most cases the organism producing the infection is different from either of these, being an extremely minute, motile rod usually measuring less than 1 micron in length and about 0.2 of a micron in width. According to Beyerinck, there is a single flagellum attached to the posterior end of these "rovers," but repeated efforts have failed to demonstrate this, although there is no question about motility.

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[a] Bot. Zeit., xlvi, 1888, pp. 725–804.

[b] Phil. Trans. Roy. Soc., London, vol. 178, 1887.

[c] Mém. de l'Académie Imp. des Sciences de St. Petersburg, Ser. VII, X, No. 6, 1866.

These minute bacteria gain admission to the plant through the root hairs, a number of them often penetrating the same hair. It requires but a short time for them to increase greatly in number, and there is then formed the strandlike colony of bacteria which has been responsible for the idea that the nodules were formed by true fungi. One of the first and most thorough investigations of these fungus-like threads was made by Ward,[a] who followed their development from the root hairs to the cells of the nodule, and came to the conclusion that the bacteria-like bodies originated by a kind of budding from enlarged portions of the "hyphæ." Because of the resemblance of this process to certain known methods of forming spores in the Ustilagineæ, he considered the cause of nodules to be due to a fungus related to this group. Eriksson,[b] Cornu,[c] Prillieux,[d] and Kny[e] have all held similar views as to the fungus origin of the nodule. Frank,[e] while at first adhering to this theory, later came to consider the nodule a natural formation of the legume root developed for the purpose of absorbing nitrogenous substances from the soil. In 1890 the same author[f] returned to the idea of an external cause and accounted for the hyphal-like structures by explaining that they were made up of the protoplasm of the cell and of bacteria-like bodies, to which he gave the name of *Rhizobium leguminosarum*. Some have held the theory that because of the resemblance of these strands to plasmodia, the cause of the nodule must be due to a myxomycete—possibly a form related to the Plasmodiophora of the Crucifereæ.

Careful investigation has demonstrated, however, that these structures resembling hyphæ are in reality nothing more than a zooglœa mass formed by the swelling of the outer layers of the extremely small bacteria which penetrate the root hairs. It is not necessary to assume the presence of minute pores in the cell walls to account for the manner in which the strand passes from one cell to another, as was done by Beyerinck,[a] for the same secretion which enables the original organism to dissolve the wall of the root hair will also in greater quantity produce the same effect upon the root tissue. Although these zooglœa masses, or "infection threads," are usually present in great numbers in the young nodules of most legumes, they do not always occur, and it is not necessary that the bacteria pass from cell to cell in this form. The lupines are particularly free from these strands, it often being difficult to find them even in the root hairs. As the nodule develops, due to the irritation set up in the cells of the root by the entrance of the bacteria, the zoogl&oelig;a threads, which were at first made up entirely of the minute bacteria, begin to develop bacteria of a larger size which may or may not be motile, according to the conditions under which they are grown. These larger rod-shaped bacteria, measuring from 2 to 5 microns in length and about 1 micron in width, as they become older usually give rise to the peculiar branching forms so frequently described and considered as being peculiar to the legume nodule.

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[a] Bot. Zeit., xlvi, 1888, pp. 725–804.

[b] Acta, Univ. Lund., 1874.

[c] Etude sur le Phylloxera, 1878.

[d] Bul. de la Soc. Bot. de France, xxvi, 1879.

[e] Bot. Zeit., 1879.

[f] Landwirthsch. Jahrb., 19, 1900.

How these branched forms originate has been the cause of some investigation and much speculation. According to Beyerinck,[a] the larger rods have an unsymmetrical, one-sided outline, slightly curved at the middle in such a way that as this swelling increases the two-armed structure is attained. The generally accepted view is that the branched forms are degenerate or involution forms of the rod-shaped bacteria, and for this reason they are frequently designated as bacteroids. Stutzer[b] regards them as a higher rather than a lower type, with which view Hiltner[c] takes issue, he considering them merely enlarged rod bacteria. Greig Smith[d] explains the so-called branching by regarding the nodule organism as a yeast, which, multiplying by budding, causes the various shapes assumed, the capsule often hindering the ready separation. While there is no reason to believe that the nodule-forming organism has any affinities whatever with the yeasts, there are good grounds for the belief that the peculiar, irregular outlines assumed are due to the fact that as a single rod-shaped form divides, it is under certain conditions unable to free itself from the enveloping capsule, and consequently two or more individuals are held together, giving the *γ* or *χ* appearance. The condition is not so unusual among the bacteria as is generally supposed, similar branching forms occurring in *Mycobacterium denitrificans* and *Pasteuria ramosa*,[e] as well as in the bacillus of tuberculosis.[f]

Further arguments against the degeneration theory of the branched forms are to be found in the fact that they can readily be produced in artificial cultures, provided the conditions are right. A faintly acid medium containing potassium phosphate will usually produce them in a short time, although they are often found upon jelly of different composition. If a solid medium is used, the surface should be covered with a thin film of water; if fluid, the amount in the flask must not be too great. Although it is generally supposed that the irregularly branched forms occur only in old nodules, this is by no means the case, as they may frequently be observed in the small, recently formed nodules of young plants.

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[a] Verh. d. Konink. Akad. d. Wetensch. te Amsterdam, **25**: 1887.

[b] Centralbl. für Bakt., Par. u. Infec., II Abt., II, 1896.

[c] Centralbl. für Bakt., Par. u. Infec., II Abt., VI, 273.

[d] Proc. Linnean Soc. of New South Wales, 34, 1899, pp. 653–673.

[e] Ann. de l'Inst. Pasteur, 2: 165. 1888.

[f] Brit. Assoc. Ad. Sci., 1015–1016. 1896. A. Coppen Jones.

CROSS-INOCULATION AND SPECIFIC CHARACTERS.

Because of the fact frequently observed that one kind of legume would not produce nodules in soil which abundantly supplied another legume with these growths, it has been supposed that each legume required a special and peculiar nodule organism. Efforts have been made to distinguish between these bacteria specifically, and separate names have been assigned to the microbes from the nodules of peas, beans, clover, etc. Most investigators, however, have been unable to discover any constant difference in the appearance and general characteristics of the bacteria of the various legume nodules, and even Beyerinck,[a] who described at least two distinct groups of these organisms, says that the failure to produce inoculation upon all legumes with one microbe is a difference in variety rather than in species. In order that such an important point might be thoroughly tested, a large number of legumes were grown in pots in the greenhouse for the purpose of testing the efficacy of various cultures derived from nodules of different hosts. The seeds were either planted in quartz sand which had been burned red-hot, or in earth thoroughly sterilized. All of the usual precautions were taken in regard to sterilizing the seed, the water, etc., and the checks proved that these methods were adequate.

It would occupy too much space to give the results of all the cross-inoculation experiments carried on, but a single example will suffice. Nodule-forming bacteria from the common pea (*Pisum sativum*), which had been grown for two weeks upon nitrogen-free media, were used for inoculating seed of the following plants: Crimson clover (*Trifolium incarnatum*), red clover (*Trifolium pratense*), white clover (*Trifolium repens*), berseem (*Trifolium alexandrinum*), alsike (*Trifolium hybridum*), sweet clover (*Melilotus alba*), cowpea (*Vigna catjang*), alfalfa (*Medicago sativa*), broad bean (*Vicia faba*), common bean (*Phaseolus vulgaris*), fenugreek (*Trigonella foenum-graecum*), hairy vetch (*Vicia villosa*), scarlet vetch (*Vicia fulgens*), yellow vetch (*Vicia lutea*), blue lupine (*Lupinus angustifolius*), and white lupine (*Lupinus albus*). In every case, with the exception of the lupines, the culture produced nodules. Out of the 25 lupine plants one had four nodules, but this was probably due to insufficient sterilization of the seed. A great many similar cross-inoculations were made in every possible combination, and it was satisfactorily demonstrated that it is possible to cause the formation of nodules upon practically all legumes, no matter what was the source of the original organisms, provided they were cultivated for some time upon a synthetic nitrogen-free medium.

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[a] Bot. Zeit., xlvi, 1888.

It is undoubtedly true that the long adaptation of the bacteria to the special conditions obtaining in a particular species of legume enables such organisms to produce more abundant nodules in a shorter length of time than bacteria isolated from some other legume and grown upon nitrogen-free media. While this is of considerable practical importance, and will probably always make it necessary to distribute the specific organism for the specific crop, it does not in any way indicate that the bacteria found in the nodules of beans, peas, clovers, etc., are separate species. The most that can be maintained is that there is a slight physiological difference due to the long association with a plant of a peculiar reaction which enables the bacteria more easily to penetrate the host upon which they have been accustomed to grow. These slight racial characteristics can readily be broken down by cultivation in the laboratory, and it is entirely possible to secure a universal organism capable of producing a limited number of nodules upon all the legumes which now possess these growths.

As the result of experiments carried on in the Laboratory of Plant Physiology and elsewhere, it is a generally accepted fact at the present time that the organism producing the nodules of the legumes is a single species of bacillus having three well-defined forms. These are: First, a very minute motile rod occurring in the soil and penetrating the root hairs, which may or may not develop peculiar strandlike zoogl≈ìa masses; second, a larger rod, measuring from 0.6 of a micron up to 2.5 microns in width and from 1.5 to 5 microns in length. This great diversity in size does not occur in the same culture or nodule, but varies according to different hosts. The larger rods are likewise motile at times, and give rise to the third form, which may appear to be variously branched, but in reality is nothing more than an aggregation of two or more rods held together by a gelatinous sheath. Spores are not known to exist.

Cultivating any of these forms upon gelatin produces slowly developing colonies of a clear, transparent appearance, which do not liquefy the medium. Similar appearing colonies occur upon various solid media without any especial characteristics to distinguish them. The organism is strongly aerobic, growing best at a temperature of from 23° to 25° C., although it may be accustomed to a temperature as high as 40° C.

There does not seem to be any necessity for creating a new group to include these organisms, as has been done by Frank, under the name of Rhizobium, for although there is a certain amount of polymorphism, it is no greater than frequently occurs in the bacteria. Consequently, the name proposed by Beyerinck of *Bacillus radicicola* would be retained except for the fact that, according to the modern interpretation of this genus, the organism must have flagellæ over the entire surface. According to Beyerinck's own statement and other observations made upon both minute and full-size rods, the flagellæ are found at but one end. For this reason it becomes necessary to transfer the nodule-forming bacteria to the genus Pseudomonas, the name then standing as *Pseudomonas radicicola* (Beyerinck).

METHODS OF CULTIVATION.

The usual method of growing the nodule-forming organism has been to make a medium from a decoction of the particular legume upon which the organism originally grew. This was the method used by Nobbe and Hiltner, and the latter[a] has gone so far as to say that they can only be grown in nutrient media containing legume extract. This, however, is not the case, the number of organic and inorganic substances in both solid and liquid media upon which *Pseudomonas radicicola* will thrive being very great. More than fifty different combinations consisting of various nutrient salts, such as magnesium sulphate, potassium phosphate, ammonium phosphate, together with peptone, sugar, glycerin, asparagin, as well as potato, cabbage, squash, etc., have been found to produce at least a fair growth, although of course an extract of the host plant, plus 1 to 3 per cent peptone, with about 2 per cent cane sugar, will give the most luxuriant growth in the shortest time. As the result of numerous trials, however, it has been found that although the bacteria increase most rapidly upon a medium rich in nitrogen, the resulting growth is usually of very much reduced virulence, and when put into the soil these organisms have lost the ability to break up into the minute forms necessary to penetrate the root hairs. They likewise lose the power of fixing atmospheric nitrogen, which is a property of the nodule-forming bacteria under certain conditions.

For this reason the mere matter of an abundant growth is one of the least desirable considerations in propagating these organisms for any practical purpose, and a medium had to be devised which, while admitting of a fair growth, would at least retain, if not increase, the ability of the organism to produce nodules and fix nitrogen. This condition was met by using an agar for plating out from the nodule to which no nitrogenous salt was added, the usual combination being 1 per cent agar, 1 per cent maltose, 0.1 per cent monobasic potassium phosphate, and 0.02 per cent magnesium sulphate to 100 cubic centimeters of distilled water. While such a medium is not, of course, absolutely devoid of fixed nitrogen, the percentage is so much less than that found in a legume extract-peptone combination that the results are quite satisfactory. Silica jelly was also used as a solid basis to which the above salts were added, giving a culture medium as free from nitrogen as could be obtained.

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[a] Selskoe Khozyaĭstvo ĭ Lyesovodstvo, St. Petersburg, 192, pp. 425–462. 1899.

Bacteria grown upon media of this character were found to be much more virulent than those cultivated on a rich nitrogenous base, and field experiments by the acre showed the greatest difference in the nodule-producing power of organisms grown by these two methods.[a] That there should be such a considerable increase in the nodule-forming and nitrogen-fixing power of these organisms when grown under different conditions is not surprising when it is remembered how susceptible the bacteria are to a change in their environment and the rapidity with which new generations are formed. Percy Frankland[b] has shown that the mere transfer of the bacillus which ferments calcium citrate from a liquid to a gelatin medium is sufficient to cause it to lose its fermenting power. Rosenau[c] found that a bacterium pathogenic to rats loses its virulence if cultivated in contact with air, and many other instances of the great rapidity with which bacteria may modify their seemingly fixed functions might be given. Therefore, one of the most important advances in developing a method of perfecting a culture of the nodule-forming microbe suitable for practical purposes consisted in getting away from the old and seemingly more natural methods of propagation and resorting to the combination which would result in producing a type of fixed virulence. It would seem that for bacteriology in general, helpful and necessary as the solid nitrogenous media have been, much information of value has been lost by abandoning some of the older and less rapid culture methods.

EFFECT OF VARYING CONDITIONS.

The influence of heat, light, alkalinity, etc., upon the organisms producing nodules is of considerable practical importance, and for this reason a number of experiments were tried to ascertain the effect of various external conditions upon the growth and efficiency of the bacteria.

LIGHT, HEAT, AND AIR.

As the result of numerous tests, it was found that except for the deleterious effect of strong sunlight there seemed to be no difference in organisms grown in the light and in the dark. The optimum temperature is from 23° to 25° C., and above 40° C. there is usually no appreciable growth. It was not possible to produce death by any degree of cold, although below 10° C. practically no multiplication took place. The presence or absence of air was found to be of the utmost importance.

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[a] Yearbook of the Department of Agriculture for 1902, pl. xlii, figs. 1 and 2.

[b] Proc. Brit. Inst. Great Brit., 13: 531. 1890–92.

[c] Bul. V, U. S. Marine Hosp. Serv., 1901.

Cultures from which the air was exhausted soon perished, and even cultures in tubes filled with air but sealed deteriorated rapidly. It is also undoubtedly true that lack of air prevents the formation of the branched forms, which are of the greatest service to the plant in supplying it with nitrogen. This is one reason for certain nodules being of little or no value to the plant, a point which will be discussed more fully in another chapter. The aeration of the medium likewise has considerable to do with increasing the ability of the organism to fix atmospheric nitrogen in liquid cultures, and the necessity for securing an ample supply of air in soil which is to be used for growing legumes can not be too strongly emphasized. An effort was made to determine whether the necessity for a good supply of air was not due to the presence of an abundance of nitrogen gas. Tubes in which the air was replaced by pure nitrogen were able to sustain vigorous cultures of the bacteria for a number of weeks, and it seems probable that this gas is really the only essential obtained from the atmosphere. The action of denitrifying bacteria in the soil, releasing large quantities of nitrogen gas, thus becomes a most important source of supply to nodule-forming organisms.

ACIDS AND ALKALIS.

So far as the growth of the organism upon culture media is concerned, the effect of acids or alkalis within reasonable limits has no decided effect. Experiments tried upon a number of bacteria from various legume nodules proved that it was possible for them to flourish in media containing as high as 0.05 per cent of calcium carbonate, as well as in media containing an equal percentage of free citric and other similar acids. Trials upon plants in pots demonstrated the fact that the bacteria would stand any degree of acidity or alkalinity of the soil that would permit the growth of that particular legume. In general, it may be said that potassium and sodium salts in strengths of from one-third to 1 per cent often entirely inhibit the formation of nodules, and less quantities reduce the formation considerably, while calcium and magnesium salts greatly favor their production. That this action is due to the production of an osmotic state prejudicial to the entrance of the organism through the root hairs, as suggested by Marchal,[a] is a possibility, but the direct effect upon the germs is also a factor which must be considered. On the other hand, there is no question that with lupines and certain other plants adapted to acid soils the addition of calcium and magnesium carbonate is as injurious to the formation of nodules as it is to the plants themselves.

The importance of neutralizing the acidity of certain soils in order to be successful in growing clover, alfalfa, etc., is well known, and the addition of lime is frequently recommended where such crops fail. In such cases it is probable that the acidity of the soil not only is prejudicial to the growth of the plant, but has likewise prevented the development of the nodule-forming bacteria. Thus, the addition of the lime serves a double purpose.

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[a] Compt. Rend., Paris, 1901, p. 1032.

According to Maze,[a] there are but two groups of nodule-forming organisms—those adapted to an acid soil, and normally found on lupine, broom, furze, etc., and those adapted to an alkaline soil, occurring upon most of the common forage and garden legumes. While experience has not borne out this theory in the United States, there can be no doubt about the readiness with which the nodule organism from calcium soils may be accustomed to live upon an acid medium, and the reverse; and there is every reason to suppose that the adaptation of special bacteria to suit special kinds of soil may be readily brought about.

NITRATES.

The fact that the nodules do not occur abundantly upon plants growing in very rich earth has been frequently observed, so that the deleterious effect of nitrogenous substances upon artificial cultures is to be expected. Alkaline nitrates in the proportion of 1 to 10,000 are sufficient to prevent the formation of nodules, and, as has already been referred to, the cultivation of the bacteria upon media containing appreciable quantities of nitrogen for any length of time is sufficient to cause them to lose both the power of infection and that of fixing atmospheric nitrogen. It will thus be seen that many of the factors influencing the size, number, and location of the nodules are those affecting the bacteria quite as much as the plant, and any information in regard to the life history of the organism, together with the physiological effect of conditions and substances with which the nodule-forming bacteria come in contact, will be of much practical importance. Plates II, III, and IV illustrate well the difference in the effect of the same bacteria upon the same kinds of plants in different soils, and fully as striking difference might be shown where the moisture, or the acidity, or the air supply varied.

MOISTURE.

Experiments by Gain[b] and others have shown that with peas, beans, and lupines, watered and unwatered, the number of nodules in moist soil exceeded those in dry soil from ten to twenty times, and experiments in this country have demonstrated most conclusively that the humidity of a soil greatly favors nodule formation. This fact must be due either to the inability of the organism to come in contact with the root hairs in the absence of sufficient moisture or to a failure to penetrate the root hairs under such conditions, for drought is in no way fatal to the bacteria.

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[a] Ann. de l'Inst. Pasteur, xi, 1897, pp. 145–155.

[b] Compt. Rend., Paris, **116**: 1394–1397.

WHERE IS NITROGEN FIXED?

Having briefly discussed some of the results obtained by the presence of nodules upon the roots of legumes, and having indicated the character of the organisms causing these growths, it is important that we inquire into the precise method by which nodules are of benefit to the plant, if, in fact, they always are beneficial. After it was definitely established that the legumes were actually able to obtain free nitrogen from the atmosphere, naturally the next question was in regard to where and how this gas was fixed. Frank advanced the theory that nitrogen entered the plant just as carbon dioxid does, the transformation into an available form taking place in the leaves in the same way that carbon is obtained. This view soon gave way to a second one, which maintained that the nitrogen was fixed in the soil by the action of the bacteria and then used by the roots in the same way that any combined nitrogen would become available. Still another idea has been that the presence of nodule-forming bacteria in a plant acted as a stimulus which enabled it to use nitrogen gas in some new and unknown manner; and, finally, the explanation has been offered that the nodules with their bacteria act as accumulators of nitrogen which afterwards becomes available for the plant through the destruction of the contents of the nodule. One of the points which might assist in establishing this latter theory would be to demonstrate that the nodule bacteria have the power of combining free nitrogen within their own cells. The chief difficulty in attempting to gain such proof is that it is readily possible that although they possess this function inclosed in the nodule, the power might be lost when removed from contact with the host plant and no fixation would take place under artificial conditions. Indeed, Mazé,[a] in discussing the fixation of free nitrogen by the nodule-forming organism, claims that it is acquired in the plant and lost in the soil. That this property is quite unstable in the bacteria of legumes there can be little doubt, and it is not surprising that many investigators have reported an absolute failure in attempting to demonstrate the fixation of nitrogen by these bacteria in pure cultures.

Experiments have shown, however, that the nodule-forming organism in the large rod stage has the property of fixing free nitrogen independent of any host plant, when grown upon the proper media and thoroughly aerated. In order to demonstrate this fact, 90 Ehrlenmeyer flasks containing 100 cubic centimeters each of culture fluid were inoculated with nodule-forming organisms from red clover, soy bean, white lupine, hairy vetch, berseem, and garden pea. The culture medium contained magnesium sulphate, potassium phosphate, and maltose, and a Kjeldahl determination showed that there was present per 100 cubic centimeters 0.0003 gram of nitrogen as nitrites, making a fluid as free from nitrogen as could be obtained under the circumstances. After inoculation, air which was first passed through a flask filled with pumice stone and sulphuric acid to remove any ammonia was drawn through the flasks by an aspirator. Precautions were also taken to prevent evaporation. Kjeldahl determinations of the inoculated and uninoculated flasks were made at the end of one, two, and three weeks, and in every case a most decided gain in nitrogen was obtained by the end of the third week. Some of the flasks failed to show any difference the first week; in fact, the analysis indicated in a few cases that instead of 0.0003 gram it was impossible to find any trace of nitrogen. This was probably due to the fact that the organism did not develop very rapidly at first and the original amount of combined nitrogen was used before any free nitrogen was fixed. It may be that this took place in all the flasks, but as determinations could not be made oftener than every seven days many of the cultures had begun to gain before the analysis was made.

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[a] Ann. de l'Inst. Pasteur, xi, 1897, pp. 145–155.

The actual gain as above determined varied from 0.0002 gram to 0.0022 gram per 100 cubic centimeters. The checks or uninoculated flasks, of which there were twelve, four being analyzed at the end of each week, at no time showed an increase over the original 0.0003 gram per 100 cubic centimeters. Thus, it would seem that there could be little doubt about the power of *Pseudomonas radicicola* to fix free nitrogen independent of any leguminous plant.

A second series of the same number of flasks was started some time after the results from the first analysis were obtained, in order to determine whether or not the nitrogen was combined with the potassium in the medium or was actually contained in the cells of the bacteria. In this set of flasks the fluid medium was varied by adding ammonium phosphate to some and glycerin to others, as well as by substituting cane sugar and peptone for maltose. The results were practically the same as in the first test, except that the percentage of nitrogen fixed was considerably greater in the flasks containing the ammonium phosphate, sometimes showing a gain of 0.0031 gram per 100 cubic centimeters in three weeks. The exact composition of this liquid was as follows: Magnesium sulphate 0.02 gram, potassium phosphate 0.1 gram, ammonium phosphate 1 gram, glycerin 1.5 cubic centimeters, maltose 1 gram, distilled water 1,000 cubic centimeters. After growth had become thoroughly established in these flasks and a Kjeldahl determination showed that nitrogen was being accumulated to a considerable extent, the remainder of the fluid was filtered through a Pasteur-Chamberland filter for the purpose of removing all the bacteria. The analysis of the filtrate, while showing a small percentage of nitrogen, established without question that a very large proportion of the gain in nitrogen was due to the enormous increase in number of the nodule organisms, each one of which contained a minute quantity of this element.

Since the legume bacteria can fix nitrogen and store it up within themselves, it becomes necessary to investigate carefully the behavior of these organisms within the nodule with a view to determining, if possible, how the nitrogen is supplied to the plant. Analyses of the nodules of legumes show that they frequently contain as high as 7 to 8 per cent of nitrogen, while other parts of the plant will not possess more than 2 per cent. This high percentage is before flowering and the formation of fruit, it being a well-recognized fact that the contents of most of the nodules disappear as the plant reaches maturity and the inclosing tissue shrivels up. Such a high percentage of nitrogen is not constant, however, there being a distinct relation between the character of the nodule and its nitrogen content. As a rule, it may be said that the abnormally large nodules contain the smallest percentage of nitrogen, the most efficient forms being those upon the smaller roots of medium size. Examination of the nodules of such sizes as to be considered unusual shows them to be filled not with branched forms but straight rods, which, as will be seen later, are not suited to supply nitrogen in any quantity. A microscopical examination of the nodule at this time will demonstrate that whereas formerly it was packed full of the branched capsulate organisms, these have now nearly disappeared, leaving only a few rodlike forms. Chemical analysis of the bacteria themselves indicates that they are largely albuminous. Frank found certain nodules developing amylodextrin, and he attempted to distinguish between the organisms forming this substance and those producing albumin. It is not believed, however, that there is any distinction to be made in the contents or substance of the organisms giving rise to the nodule.

The young nodule is at first packed with rod-shaped bacteria and is of a pale red color, changing to greenish gray as the nodule matures and the rods become transformed into the various irregular branched forms so characteristic of these bacteria. Finally, the cells of the roots are able to secrete an enzyme which dissolves the nodule organism when in the branched condition, and by this means renders available considerable quantities of nitrogen, which is then diffused through the plant. This method of absorbing the contents of the nodule is facilitated by the structure of the nodule, which, according to Van Tieghem,[a] originates in the pericycle of the mother root opposite or on each side of the woody bundles. Sometimes the nodules possess from two to four distinct central cylinders, inserted one above the other, at points in the woody bundle of the central cylinder of the mother root. Because of their origin, structure, and disposition, there can be little doubt about nodules being morphologically merely rootlets that have enlarged, the first investigation calculated to establish this fact being made by Van Tieghem[a] and later reaffirmed by Peirce.[b]

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[a] Bul. de la Soc. Bot. de France, **35**: 105–109.

NODULES NOT ALWAYS BENEFICIAL.

That the bacteria are almost always able to resist the action of the host plant, except when in the branched condition, is undoubtedly true, although there are a few exceptions in the case of the pea and one or two other plants. If the only source of nitrogen is by dissolving the bacteria, it will readily be seen that should the nodules continue to be filled with the unbranched rods the benefit to the plant will be little or nothing, and the presence of nodules upon the roots may even be a detriment. Too little attention has been paid to this point, the almost universal opinion being that all nodules are able to supply nitrogen to the plant, and any failure in a crop well supplied with these growths must be due to other causes. This is not the fact, however, there being no question that frequently the organisms producing nodules have lost the power of going into the branched condition; and thus, while preventing their destruction by the plant, they defeat the very object for which they are supposed to be so valuable. That this condition is due to the organism itself, and is not the result of lack of vigor on the part of the plant which prevents its secreting the enzyme that will make the bacteria available, is proved by the fact that it is possible to control this situation by modifying the character of the bacteria. Thus, if nodule-forming organisms be grown upon artificial media for a long time, where they are almost invariably in the rod condition, this form becomes so firmly established that plants inoculated with such cultures, although forming nodules, receive practically no benefit, the nodules remaining firm and hard and furnishing no nitrogen to the roots.

It is precisely the same as trying to furnish a plant with its supply of calcium or potassium in an insoluble form. These essentials of plant food may be present, but so long as they remain fixed and will not pass into solution they are valueless to the plant. The nodule organism of most legumes, so long as it retains the rod form, is insoluble, and the plant must be supplied with bacteria capable of passing into the branched stage under the conditions existing in the nodule if they are to be of service. Thus it is plain that the nitrogen is fixed not by the plant but by the bacteria within its roots, and this element becomes available to the plant only on account of its ability to dissolve and absorb these nitrogen-containing bodies. Consequently, there is after all no conflict with the original dictum of Boussingault that the higher plants can not use directly the nitrogen of the atmosphere. It is no more proper to insist that the legumes themselves can combine nitrogen gas than it is to claim this function for wheat or potatoes. The ability to absorb bacteria rich in nitrogen is the only property peculiar to the nodule-bearing plants. If nematode worms were largely nitrogenous, and violets and other plants infected by them were capable of destroying and absorbing these parasites, it would be just as correct to term the nematode-infected plants "nitrogen-fixing" as it is to ascribe any such function to the legumes.

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[a] Bul. de la Soc. Bot. de France, 35: 105. 1888.

[b] Proc. Cal. Acad. Sci., 2, June, 1902.

SYMBIOSIS OR PARASITISM?

Granting the facts just stated, we are at once confronted with the old idea of the supposed symbiotic relation between the bacteria and the plant. Painful as it may be to disturb one of Nature's mutual benefit societies, there seems to be no other way than to consider the nodule-forming bacteria as true parasites which penetrate the roots of the plant for the purpose of obtaining the necessary carbohydrates for food. Fortunately for the host plant, there are certain conditions under which it can overcome the bacteria and eat them up, as it were, thus obtaining a considerable amount of nitrogenous food which would not otherwise have been available. That there is anything ideal or truly symbiotic (in the sense that De Bary used the term) about this arrangement is difficult to comprehend. The only cooperation between bacteria and host seems to consist in the microbe having the best of the situation at first, when it is able to secrete substances injurious to the cells of the legume, and later the host plant retaliates by secreting still other substances which result in the complete destruction of most of the bacteria. So long as it was maintained that the nodule organism could only grow in the root of a legume or upon an extract of these plants, as was claimed by Hiltner[a] and many others, there might have been some slight foundation for the theory, but even this basis is now gone. While not agreeing with Peirce[b] in considering it difficult to understand how the leguminous plant as a whole can benefit by an association with *Pseudomonas radicicola*, which is injurious and finally destructive to the cells in which the bacteria occur, his conclusion regarding the parasitic nature of these bacteria is undoubtedly correct.

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[a] Selskoe Khozyaĭstvo ī Lyesovodstvo, St. Petersburg, 1899, pp. 425–462.

[b] Proc. Cal. Acad. Sci., 2, June, 1902.

INFECTION AND FIXATION OF NITROGEN WITHOUT NODULES.

The wide distribution by the Department of Agriculture of cultures for the purpose of experimenting with the artificial inoculation of the soil has led to some very interesting results, some of which may have a considerable bearing upon the final perfection and success of the method now in use. One of the most striking effects reported by some careful observers was the apparent beneficial action of the culture without the formation of nodules. In one instance at a State experiment station three plots of soy beans were planted, one inoculated with a Department of Agriculture artificial culture, another treated with soil from a field which grew nodule-covered soy beans in abundance, and lastly an uninoculated plot for the purpose of checking the other two. The soil for the three experiments was as nearly alike as possible, and the treatment, except as to inoculation, was precisely the same. As the season advanced it was noted that the check plot developed no nodules and rapidly failed; the plot inoculated by the transfer of soil produced nodules and made a fair average growth, but the plot treated with the artificial culture far exceeded it in every way. This was not so surprising until an inspection of the roots showed the entire absence of nodules. No explanation could be offered at the time, but later, when practically the same conditions were noted in some experiments with berseem in the West, plants were secured which threw some light upon the situation. As the result of a careful microscopical examination of the roots, it was found that although no nodules were evident—in fact, did not exist—the cells within the smaller roots were packed with the characteristic branching forms of *Pseudomonas radicicola*, and that undoubtedly the plant was able to obtain considerable benefit from the presence of these organisms.

The same condition has been found in alfalfa, and it is presumed that it was this internal infection which was encountered several years ago in white lupine, although not recognized at the time. Plate V illustrates most strikingly the difference which may occur in plants producing normal nodules and those inoculated but showing no external evidence of infection. The small bunch of alfalfa plants was grown upon rich creek bottom land which had been overflowed and inoculated by the carrying in of bacteria from a melilotus field. These plants were abundantly supplied with nodules. The larger plants were grown upon the same farm, but upon sandy upland where no legumes had been previously planted. Consequently, the seeds were inoculated with a culture supplied by the Department and with most satisfactory results. There was, however, no evidence of nodules, and not until after a microscopical examination of the roots was it known that they were thoroughly infected with nitrogen-fixing bacteria.

Since the production of this peculiar result under control conditions has not as yet been possible, it is difficult to conjecture just what circumstances would produce such an effect. It was undoubtedly of advantage to the plants in all of the known cases and may be a much more universal phenomenon than is supposed. Of course, wherever nodules are produced abundantly there will be little opportunity for detecting internal infection. The absence of nodules in poor soil upon a crop that was failing would seem to indicate that no nitrogen was being fixed and that no bacteria were present. Where legumes have been successful without nodules it has generally been supposed that the soil was rich enough in nitrogen to support the plant and that the requisite bacteria either had never found their way into the soil or because of the excess of nitrogen had been prevented from developing. Cases of this character must be more fully investigated before it is known how frequently inoculation without nodules may occur. That it is not an impossibility is sufficiently evident to warrant further study.

INOCULATION BY PURE CULTURE.

As has already been shown, in order to secure artificially a satisfactory inoculation of any leguminous crop it is necessary that the greatest precaution be taken in procuring the original culture. The method of growing the organism upon some medium relatively free from nitrogen is important in order that its virulence may not be lost, and from the time the bacteria are plated out from the nodule until they are introduced into the soil, every effort must be made to preserve and increase as far as possible the nitrogen-fixing and root-penetrative power of these organisms. Even though the efficiency of the culture be at its highest point, the mere fact of its having to grow for a considerable time under artificial conditions is apt to weaken it; consequently, the means of preserving and distributing the bacteria after they are propagated are fully as important as the method of obtaining them in sufficient quantity for such distribution. This is another reason why the nodule-forming bacteria sent out upon rich nutrient media failed to maintain their original strength, and if it had not been possible to devise some more satisfactory way of delivering these organisms to the farmer, it is probable that but little success could ever have been attained by the pure-culture method. Fortunately, however, although *Pseudomonas radicicola* does not produce spores, the large rods will withstand desiccation for a year or more, and therefore, because they may be sent dry any distance and upon being revived be in the same condition of efficiency with which they started, the problem becomes a very simple one.

The method which has been employed in the Department of Agriculture for the past year has been to saturate absorbent cotton in a liquid culture of the nodule-forming organism. In this way millions of the bacteria are held within the cotton, and after this is carefully dried out they remain dormant in much the way that seeds do, waiting for the proper conditions to revive them. Where it is possible to obtain sterile utensils and to prevent absolutely the entrance of micro-organisms it is sufficient to insert the inoculated cotton into sterilized water, when in the course of time the bacteria will have multiplied sufficiently to produce a decided clouding of the culture and will be ready to introduce into the ground. This would require too long, however, and it is also difficult, when preparing to treat large quantities of seed, to prevent the entrance of other bacteria, molds, yeasts, etc., all of which may have a deleterious effect upon the growth of the nodule-producing organism. For this reason it has seemed best to prepare the water in such a way as will facilitate the growth of the desired bacteria and yet delay or prevent the development of the forms which might be introduced from the outside. Consequently, two packages of nutrient salts have been distributed with the cotton culture, one containing sugar, magnesium sulphate, and potassium phosphate, and the other ammonium phosphate. (See Pl. I.) By the addition of the first three ingredients to the water containing the cotton saturated with bacteria a solution is formed which is not well adapted for the growth of the organisms usually carried about in the air, but is well suited for the multiplication of the nodule-forming bacteria. The addition of the ammonium phosphate at the end of twenty-four hours tends to increase still further the growth of these bacteria, which are already well started if the temperature has not been too low or too high.

METHODS OF USING LIQUID CULTURE.

After the water containing the nutrient salts and bacteria-laden cotton has been allowed to stand until it becomes milky with the nodule-forming organisms, it is necessary to introduce this culture into the ground. This may be accomplished in two ways, either by moistening the seeds with the fluid, the bacteria adhering to their surfaces and consequently being in close proximity at the time of germination, or by mixing earth or sand with the culture and spreading over the field as one would apply fertilizer. Greenhouse and small-plot experiments indicated no particular advantage of one method over the other, and the hundreds of reports received from all over the country show that either means of introducing the organisms will produce satisfactory results if the directions are properly followed. The sheet of directions which has accompanied each package of inoculating material as distributed by the Department of Agriculture reads as follows:

DIRECTIONS FOR USING INOCULATING MATERIAL.

(*Method patented in order to guarantee the privilege of use by the public. Letters Patent No. 755519 granted March 22, 1904.*)

Put 1 gallon of clean water (preferably rain water) in a clean tub or bucket and add No. 1 of the inclosed package of salts. Stir occasionally until all is dissolved.

Carefully open package No. 2 and drop the inclosed cotton into the solution. Cover the tub with a paper to protect from dust, and set aside in a warm place for twenty-four hours. Do not heat the solution or you will kill the bacteria—it should never be warmer than blood heat.

After twenty-four hours add the contents of package No. 3. Within twenty hours more the solution will have a cloudy appearance and is ready for use.

To inoculate seed.—Take just enough of the solution to thoroughly moisten the seed. Stir thoroughly so that all the seeds are touched by the solution. Spread out the seeds in a shady place until they are perfectly dry, and plant just as you would untreated seed. If bad weather should prevent planting at once, the inoculated seed, if thoroughly dried, may be kept without deterioration for several weeks. The dry cultures as sent from the laboratory will keep for several months. Do not prepare the liquid culture more than two or three days previous to the time when the seeds are to be treated, as the solution once made up must usually be used at the end of forty-eight hours.

To inoculate soil.—Take enough dry earth so that the solution will merely moisten it. Mix thoroughly, so that all the particles of soil are moistened. Thoroughly mix this earth with four or five times as much, say half a wagonload. Spread this inoculated soil thinly and evenly over the prepared ground exactly as if spreading fertilizer. The inoculated soil should be harrowed in immediately.

Either of the above methods may be used, as may be most convenient.

TIME OF INOCULATION.

The results of numerous laboratory experiments have seemed to demonstrate that it is impossible for the nodule-forming bacteria to penetrate the roots of legumes after they have attained an age of from two to four weeks. Maria Dawson[a] found that plants having roots from 1½ inches to 2 inches long produced no nodules, while those with roots only about one-half inch in length were thoroughly inoculated with the same culture. For this reason it has been considered that it was useless to attempt to add the nitrogen-fixing bacteria to a growing crop, and the directions were adapted to be used at the time of seeding only. Practical experience in the field, however, has given some results which would seem to indicate that under some circumstances the use of inoculating material upon a standing crop of any age will be of benefit.

F. G. Short, of Fort Atkinson, Wis., writes:

> In July the Department sent me a sample of alfalfa bacteria, with directions for application. This was used on a field of alfalfa which had been newly seeded this spring and up to that time had shown a very small growth of yellow, rather stunted plants. I used the bacteria according to directions and can see there is quite a decided change for the better.

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[a] Phil. Trans. Roy. Soc., London, 1899, p. 21.

John C. Lloyd, of Utica, Nebr., used a culture upon 5 acres of alfalfa sown three years ago. The result was "ranker growth than before treatment and much heavier crop of hay. Cut three times and could have cut four, but pastured the last crop."

In Hoard's Dairyman for November 11, 1904, an account is given of the treatment of old alfalfa fields with liquid culture applied by means of a street sprinkler. An experimental trial of this method was made by one of the editors of the paper with "very evident success."

From Levy, Mo., Thomas O. Hudson writes regarding a field of alfalfa planted in 1901 and treated with inoculating material in March, 1904:

> Results good. It was sickly and yellow and spindling, and did not do any good until this year. This year it was dark green and thrifty. I think it will be better next year.

Another report upon an alfalfa field to which bacteria were added during the fourth year was recently sent by U. J. Hess, North Yakima, Wash.:

> The crop, which had been short, pale, and spindling, took on a darker color and a rank growth and yielded, I think, about three times as much as formerly.

The same results have been noted for clover, H. W. Dunlap, Holland Patent, N. Y., reporting that having more of the liquid culture than could be used for some seed he was inoculating, he mixed it with a light loam and spread it upon a part of a field already in clover. The difference in color and size of the plants later on indicated where the soil had been distributed.

Mrs. J. A. Wells, of Bryn Athyn, Pa., tried watering pea vines a month old, with undoubted success, and the results of a similar treatment by John R. Spears, of Northwood, N. Y., are shown on Plate X. Mr. Spears treated his peas with the culture solution with the exception of one row, after they were two or three inches high, and the decided benefit is indicated by his report printed elsewhere in this bulletin.

In the light of these and similar experiments, there can be no doubt that bacteria of a high state of virulence are capable of producing inoculation at practically any time during the life of the legume if the conditions in the soil are favorable. It is probable that similar results have not been previously noted because bacteria of such high efficiency have not been used. While it can not be stated that as satisfactory an inoculation will be obtained in this way as by treating at the time of planting, it certainly seems that under most circumstances where a crop is failing for the lack of nitrogen-fixing bacteria it is worth while making an effort to introduce them, even though the plants be several years old.

WHEN INOCULATION IS UNNECESSARY.

Since the only purpose of the bacteria added to the soil is to furnish nitrogen to the plants in an available form, usually within root nodules, it is evident that where the organisms are already abundant and the crop is thriving, but little benefit can be expected from an additional inoculation. Of course, the nodules may be of the parasitic kind, furnishing little or no nitrogen, or they may be insufficient in quantity, in which case the addition of a fresh lot of bacteria may produce beneficial results. A considerable number of reports have been received, indicating that even with such universally distributed organisms as those occurring on cowpeas and red clover, the artificial inoculation of an old field produced a noticeable increase, and there is every reason to believe that where the land contains bacteria of a less degree of virulence than those sent out in the Department cultures, an inoculation is worth while. On the other hand, it should be remembered that many fields are thoroughly supplied with bacteria of the highest efficiency, and no additional supply, however abundant, will increase the yield.

Inoculation would also be of little, if any, benefit to a rich soil containing a large amount of available nitrogen. As has been shown, the nitrogen-fixing bacteria will not grow well under such conditions, and being in an enfeebled stage the plants are able to withstand their action. Furthermore, the earth already being supplied with a sufficient amount of nitrogen, the plants will draw upon this direct source and produce as abundantly as if provided with nodules. This condition, however, is very undesirable for leguminous crops, and they should not be grown upon such a piece of land unless poorer soil can not be obtained, or unless a legume is the most profitable crop for that region. The use of artificial cultures is preeminently designed for poor soil which it is desirable to bring into condition for producing some root or grain crop demanding large amounts of nitrogen.

WHEN INOCULATION IS NECESSARY.

All legumes grown either for the purpose of enriching the soil or for the crop must, in order to be of the greatest benefit to the land and the plants, be provided with the nitrogen-fixing bacteria. It is believed that the artificial culture is the method most efficient, cheapest, and freest from objectionable qualities. For these reasons inoculation should *always* be practiced under the following conditions:

(1) On poor land which has not previously grown legumes.

(2) On land which, although planted to legumes, has not produced a crop, and the roots of which legumes, upon examination, fail to show the presence of nodules.

It is probable that good results will follow the artificial introduction of bacteria if—

(1) The legumes to be planted belong to another group than those already cultivated upon the land.

(2) The same crop is to be planted upon land which previously produced a yellow and sickly lot of legumes possessing nodules which, instead of being a benefit, acted as parasites.

If the conditions favor the trial, good results *may* be obtained from the use of pure cultures when—

(1) The crop has already been planted and gives evidence of failure due to the absence of bacteria in the soil.

(2) A field which has previously grown good crops of legumes begins to give even a slight evidence that, all other conditions being the same, it is not producing the highest yield. This situation is the hardest to detect, because it depends upon a gradual loss of virulence of the bacteria already in the soil, and the only way of being certain of this condition is to try inoculation and note results.

WHEN TO EXPECT FAILURE WITH INOCULATION.

Failure with inoculation may be expected—

(1) When the directions for preparing the culture media are not carefully followed.

While the method is so simple that anyone observing ordinary care can have no difficulty in securing the proper growth, it is absolutely essential that the few necessary instructions be observed. The fact that thousands of farmers throughout this country with nothing but the printed directions have been able to obtain such satisfactory results is proof that no special knowledge of bacteriology is necessary in preparing and applying the culture fluid. Placing the solution upon ice before it has had time to develop the bacteria, planting the unopened packages in a hole in the ground, pouring the liquid culture into small depressions at intervals of a rod or more, and similar procedures contrary to the directions will not have the effect desired. Unfortunately, the distribution of bacteria for the purpose of increasing the nitrogen supply can not be as definite and complete as if a finished product were sent out. The culture does not itself contain the nitrogen, but simply the organisms which potentially possess the power of fixing nitrogen, and which, if properly handled, will increase in such numbers as to be of material benefit to the plants with which they become associated.

Plate VI will illustrate the difference in results obtained from disregarding directions and from properly following them. Figure 1 represents the best of a very few plants remaining upon a field planted and inoculated more than a year and a half ago. The result was a failure, but because some question was raised as to whether proper care had been observed in preparing the culture another package of cotton saturated with bacteria from precisely the same lot as the first was sent, with instructions to use especial care in making and applying the solution. The result of the second trial is shown in figure 2, the plants being about two months old.

(2) When the ground is already thoroughly inoculated.

(3) When the soil is so rich in nitrogen as to prevent the growth of nodule-forming bacteria.

(4) When the soil is too acid or too alkaline to permit the development of either plants or bacteria.

(5) When the soil is deficient in other necessary plant foods, such as potash, phosphorus, etc., as well as nitrogen.

It should also be borne in mind that no amount of inoculation will overcome poor results due to bad seed, improper preparation and cultivation of the land, and decidedly adverse climatic conditions.

RESULTS.

All of the foregoing discussion regarding the benefits to be derived from inoculation and the methods devised for propagating and distributing the nitrogen-fixing bacteria amounts to nothing unless it can be shown that these cultures really accomplish, under the general conditions to be found upon any farm, a decided increase in a crop over one grown without inoculation. In order that the bacteria might have the most thorough practical test possible, the Department of Agriculture has for the last year conducted one of the largest experiments of its nature ever undertaken in any country. By the free and unlimited distribution of cultures to practically everyone who was sufficiently interested to request a package, it has been possible to secure about 12,500 tests, under the most varied conditions, in almost every State of the Union. The following list indicates the number of packages distributed up to November 1, 1904.

TABLE I.—*Number of packages of inoculating material (or inoculated seed) distributed from November, 1902, to November, 1904; arranged by States, Territories, and foreign countries.*

State or Territory.	Alfalfa.	Clover.		Pea.			Bean.			Vetch.	Miscellaneous.	Total.
		Red.	Crimson.	Common.	Cowpea.	Field.	Common.	Soy.	Velvet.			
Alabama	242	17	80	10	45	1	7	10	8	109	79	608
Alaska	......	1	......	1	......	......	......	......	....	......	......	2
Arizona	11	......	......	......	......	......	......	......	2	......	1	14
Arkansas	64	15	1	9	28	1	5	2	....	2	10	137
California	171	21	4	61	15	120	41	3	1	30	23	490
Colorado	20	3	......	8	3	1	9	......	....	1	2	47
Connecticut	30	9	......	8	1	......	6	4	....	1	4	63
Delaware	10	2	10	2	3	......	1	......	....	2	3	33
District of Columbia	28	12	6	6	2	......	5	......	2	6	4	71
Florida	40	7	4	22	28	1	28	1	21	17	15	184
Georgia	89	17	26	16	15	5	5	4	3	45	62	287

TABLE I.—*Number of packages of inoculating material (or inoculated seed) distributed from November, 1902, to November, 1904, etc.*—Continued.

State or Territory.	Alfalfa.	Clover.		Pea.			Bean.			Vetch.	Miscellaneous.	Total.
		Red.	Crimson.	Common.	Cowpea.	Field.	Common.	Soy.	Velvet.			
Hawaii	4	1	......	1	2	......	1	2	2	......	......	13
Idaho	16	17	3	4	......	2	4	1	....	4	3	54
Illinois	147	101	3	17	39	3	11	33	1	8	48	411
Indiana	239	103	5	6	31	2	2	16	1	6	36	447
Indian Territory	10	4	......	1	......	......	1	......	....	......	......	16
Iowa	91	41	2	7	6	2	7	9	....	4	32	201
Kansas	122	32	......	7	13	1	11	10	....	2	11	209
Kentucky	66	55	8	13	22	1	5	9	....	8	31	218
Louisiana	50	3	1	6	14	......	1	......	1	3	25	104
Maine	12	21	......	9	......	......	11	1	....	2	5	61
Maryland	91	28	6	8	13	1	6	7	1	4	9	171
Massachusetts	71	73	3	71	6	4	48	11	....	8	10	305
Michigan	95	95	8	20	9	5	28	10	2	4	26	302
Minnesota	34	38	2	6	......	......	6	1	....	3	5	95
Mississippi	87	3	4	2	5	......	1	1	....	20	19	142
Missouri	211	63	6	10	20	......	8	13	....	7	29	367
Montana	34	10	......	1	......	1	......	......	....	......	4	50
Nebraska	96	19	......	2	4	......	3	3	....	4	6	137
Nevada	3	......	......	......	1	......	......	......	....	......	1	5
New Hampshire	11	22	......	13	2	......	8	2	....	2	8	68
New Jersey	68	32	12	9	7	4	14	2	....	5	3	156
New Mexico	18	2	......	2	......	......	2	......	....	......	......	24
New York	285	174	19	73	25	18	77	30	1	21	31	754
North Carolina	200	54	64	8	48	3	5	11	5	67	38	503
North Dakota	25	16	......	4	......	2	4	......	....	1	4	56
Ohio	273	157	9	20	23	2	24	25	2	10	55	600
Oklahoma	72	2	2	1	12	......	2	4	....	1	4	100
Oregon	126	99	3	23	2	6	15	3	....	61	7	345
Pennsylvania	128	108	15	63	14	3	46	17	....	13	......	407
Philippine Islands	1	......	......	......	......	......	......	......	....	......	......	1
Porto Rico	3	2	......	2	3	......	3	1	2	......	2	18
Rhode Island	6	5	3	3	......	......	4	3	1	1	......	26
South Carolina	70	15	48	8	28	......	5	1	....	35	31	241
South Dakota	28	8	......	5	1	1	3	2	1	1	2	52
Tennessee	185	55	7	17	26	1	10	5	2	9	29	346
Texas	276	10	3	13	28	6	7	2	2	3	77	427
Utah	1	......	......	2	......	......	2	......	....	......	......	5
Vermont	23	21	1	6	1	......	8	2	....	......	2	64
Virginia	541	184	68	26	114	2	7	48	5	56	86	1,137
Washington	106	81	1	27	3	4	24	3	....	22	3	274
West Virginia	34	19	2	5	13	......	3	6	....	2	3	87
Wisconsin	51	45	3	13	8	4	10	11	1	7	7	160
Wyoming	14	......	......	1	......	......	1	......	....	......	......	16
FOREIGN COUNTRIES.												
Australia	2	......	......	1	1	......	......	2	....	1	......	7
British Guiana	1	......	......	......	......	......	......	......	....	......	......	1
Canada	6	6	......	2	......	1	1	1	....	1	......	18
Costa Rica	2	......	......	......	1	......	......	1	1	......	......	5
Cuba	3	......	......	2	5	......	1	2	2	1	1	17
England	2	1	1	......	......	......	3	......	....	2	1	10
France	......	3	......	3	......	......	......	......	....	......	......	6
India	2	......	......	2	3	......	3	......	3	......	......	13
Mexico	3	......	......	......	......	......	......	......	....	......	1	4
South Africa	1	1	1	......	1	......	1	2	....	1	......	8
Unclassified	378	146	79	90	370	8	122	54	13	24	3	1,287
Total	5,129	2,079	523	778	1,094	216	676	391	86	647	871	12,490

REPORTS.

While it has been impossible to receive reports from all experimenters, the percentage of replies has been unusually large and is quite sufficient to enable the formation of a fair opinion as to the value of the cultures distributed. In calling for a report it was, of course, understood that in some cases where the culture was used the resulting crop could not be a success, and the users were asked to indicate, as far as possible, when the failure was evidently due to some fault of seed or weather. Likewise, if the soil was shown to have been stocked previously with the proper bacteria and good crops were produced, the use of inoculating material was not expected to be of benefit, and no difference would be detected between treated and untreated land. It is obviously difficult, however, to get all experimenters to make a note of these conditions, a report upon the general result being about all that can be expected in most cases. For this reason the summary of the reports is not as favorable for inoculation as it probably would be if all of the experiments could have been followed in the same way as is possible when such investigations are conducted upon a small scale. It should also be remembered that no selection of the region in which tests were to be made was possible. Experiments with inoculated seed of crops manifestly unadapted for the locality in which they were sown which were reported as a failure of the inoculating material have been recorded as such. In spite of counting unfavorable reports of this kind, which by no fair adjustment should be included, but which, on account of the impossibility of being certain of the conditions, could not be thrown out, the average percentage of failures is less than is generally expected from the indiscriminate planting of seed known to be good.

The tabulated reports so far as received up to November 15, 1904, for all of the principal crops are as follows:

TABLE II.—*Reports of experiments with principal crops.*

	Total reports.	Inoculation resulting in definite increase of crop.	Failures definitely ascribed to bad season, poor seed, weed growth, etc.	No increase in crop; organisms already present in the soil.	No evident advantage from inoculation; nodules not formed.	Percentage of failure.[a]
Alfalfa	1,043	522	287	59	175	25
Red clover	532	302	116	84	30	9
Garden pea	184	102	32	32	18	15
Common bean	174	85	39	23	27	24
Cowpea	290	148	42	68	32	17
Soy bean	129	54	22	11	42	43
Hairy vetch	53	28	13	3	9	24
Crimson clover	49	27	15	4	3	10
Field pea	22	14	4	4	....	....
Velvet bean	10	5	3	1	1	16
Alsike	7	3	1	2	1	25
Sweet pea	7	5	....	2	....	....
Berseem	2	1	....	....	1	....
Total	2,502	1,296	574	293	339	26

[a] In computing the percentage of "failures," the number of cases where there resulted no evident advantage from inoculation (fifth column) has been compared with the number which were positive successes (second column), no allowances being made for experiments carried on under conditions precluding any chance of success.

The following reports have been selected with a view to showing the results obtained by using the cultures sent out by the Department of Agriculture upon various crops in practically all of the States where they can be grown. It is believed that a careful examination of the replies received from so many different experimenters who have had no other instructions than those sent with the inoculating material will demonstrate the success of the new methods devised by the Department in a way that would be impossible by a mere discussion of results obtained in the laboratory or greenhouse.

ALFALFA.

ALABAMA, *Clayhatchie.* E. A. Thompson.—The few plants which were not overcome by the drought show that the inoculation was effectual.

Opelika. Cecil G. Lee.—The nodules formed on the roots, and I have a good stand.

Tuscaloosa. T. J. Ozment.—Seed treated with the bacteria produced 100 per cent more than untreated seed.

ARKANSAS, *Mount Ida.* D. Peters.—Made a crop where it would not grow before. Am of opinion that the inoculation is all right.

CALIFORNIA, *Sanger.* E. C. Southworth.—I had only material enough to inoculate 5 acres; seeded 25 acres to alfalfa. The inoculated seed grew, the other did not. I used it with such success last winter that I feel that I must have it for all this winter's seeding, and am anxious to secure enough for about 900 pounds of alfalfa seed.

Mecca. E. Brauckman.—I am glad to state that the inoculation of the alfalfa field is a success. The soil is, or was, exceedingly salty, growing nothing but saltwort and bushy samphire. I had grave fears whether the microbes could flourish in such soil.

Mesa Grande. Morgan R. Watkins.—The crops (alfalfa and cowpeas) were far in excess of the best results heretofore, though planted on the poorest soil and in the driest weather. Other plantings were absolute failures.

CONNECTICUT, *Granby.* Daniel P. Cooley.—The nodule formation is perfect. No crop has been harvested this season. Has been cut four times to kill weeds. The stand at this date (October 20, 1904) is good.

Marbledale. J. E. Watson.—No alfalfa has ever before grown for me except in a well-prepared seed bed. I have a good stand of alfalfa where I sowed it; have cut it twice and will do so again later in the season. Am forced to believe in its value [i. e., of the inoculating material].

DELAWARE, *Townsend.* James Flanagan.—A heavy storm just as plants came up covered many of them, but those remaining looked nicely and have bacteria nodules on the roots.

IDAHO, *Freese.* I. E. Lobaugh.—Made fine growth for first year. Good stand. Clipped three times. Left on ground.

ILLINOIS, *Hillsboro.* Thomas S. Evans.—The field of alfalfa is perfect; whole field deep rich green, not a single pale or yellow plant. If it does not winterkill it will be the first successful attempt in growing this legume in this section, which success is without doubt due to your inoculating material.

Mount Carmel. W. F. Chipman.—Nodule formation on almost every plant examined yesterday, and foliage rich dark green. Fine, vigorous stand. I find more nodules on the alfalfa sown about a month ago than on that sown last May. The reason perhaps is the difference in the amount of ground covered with each package, the first being about 9 acres, while the last was spread over but 1 acre.

ILLINOIS—Continued.

Mount Morris. D. E. Brubaker.—I find nodules quite evenly distributed over the entire plot of 1 acre. Am much pleased with the success. I saturated seed instead of soil. Three cheers for the discovery.

Mount Morris. A. W. Brayton.—A portion of the field is like the larger plant sent you; apparently the inoculation did good work here. (See Plate VIII.)

INDIANA, *Aurora.* E. L. Cannon.—I have got a fine stand. I sowed 300 pounds lime per acre on the clay land; then harrowed. I drilled 3 pecks of oats per acre. I cut 40 bushels oats per acre. Then we had a severe drought. The alfalfa died down, but as soon as we had rain it came up from the roots. It is fine. I got a good crop of oats and a good stand of alfalfa. I have a near neighbor who sowed oats with his alfalfa, mowed them, and left them on the ground for a mulch. He has not nearly as good a stand as I have. He did not inoculate.

Butler. L. G. Higley.—Bacteria for alfalfa was received in good condition about May 1. I prepared it and mixed it with about 20 bushels of rich soil and sowed it on the field after plowing it. I sowed my alfalfa seed May 11, along with 2 bushels of smooth barley per acre. It has done better than any alfalfa that I ever sowed. It stands over a foot high nearly all over the field. There is hardly a square foot of land in the field that is not well set with plants. I took a spade to-day and went in the field to see if I could find any trace of the bacteria, and I soon found that the soil was full of it, every plant having lots of the nodules on the roots. I then went to a field of 2-year-old alfalfa, which never was treated with bacteria, to see if there were any nodules there, and after hunting a long time I found a few very small nodules, but hardly enough to be really worth mentioning. This field is failing and I will have to plow it up. Alfalfa will grow on real rich soil without its bacteria, but I believe it will grow better with it; and if the land is the least bit poor it will starve to death if it has not its bacteria.

INDIAN TERRITORY, *Pecasset.* Don Nolian.—We had tried it (alfalfa) twice before, this being the third trial. Had perfect stand and have cut three crops and have good covering for winter. There is about 1 acre in lot, and I have taken about 3 tons of hay from it, or a ton at each cutting.

IOWA, *Algona.* Judge W. B. Quarton.—I took one gallon of nice rain water and followed the directions received from your Department with the culture of bacteria, and received the identical results that your Department said I would. I personally inoculated this bushel of seed, then spread it out to dry, took it to the farm the next morning, and planted the seed. * * * I have been upon my farm many times between the middle of July and this writing, taking my pocketknife and digging down to the roots of the alfalfa plant. I have never failed to find plenty of thrifty looking tubercles on the roots, they ranging from one to clusters of one hundred, and I am satisfied that my field is thoroughly and completely inoculated, and I believe that your method is a complete success. * * * I feel like congratulating your Department upon the very thorough and practical work that you are doing in the line of plant industry and especially as to leguminous plants. I hope that you will continue it, because the legume is the one plant, above all others, that fertilizes the soil and at the same time furnishes the protein necessary to balance the food ration in our corn-growing States like Iowa.

Garwin. William S. Dobson.—Good. Seed came up and grew. Had tried same field in alfalfa the year before, but did no good. Has proved inoculation a success. Many have tried alfalfa experimentally in central Iowa, but with indifferent success.

Iowa—Continued.

Hornick. George O. Shedd.—The stand is good. I thought that it would die on the thin, poor, yellow places, but looks now as though it may not. Treated 1 bushel, sowed 4 acres.

Kansas, *Arkansas City.* Rufus R. Marsh.—The seed was used on sandy knolls in field, and made better showing than balance of field without inoculation.

Halstead. G. R. McWilliams.—The inoculated seed has a good colored plant; the uninoculated plants were yellow and did not make any hay. I would not try alfalfa without inoculating the seed.

Halstead. A. Murray.—The alfalfa inoculated could not have done better. I will not plant any after this without inoculation. I think inoculated alfalfa is as good at 1 year old as uninoculated is at 3 years old.

Holton. R. J. Linscott.—Harvested three crops of hay. An exceedingly thick, even stand. Plenty of bacteria on roots. A success in every way. Hope I can treat alfalfa seed this way every time I sow it, as I never had a successful stand before.

Holton. S. K. Linscott.—All that could be desired. At seven weeks from date of planting it was 10 inches high in some places. Every root so far examined has from one to six nodules. Many thanks for your kindness.

Stockton. J. J. Coppersmith.—Proved very satisfactory. Did about one-fifth better than that not treated, but other chances equal. Amount, 3½ acres; first cutting, 3 tons; second, 5 tons.

Kentucky, *Berlin.* John A. Buser.—One acre was planted; one half was inoculated, the other half was not. Received good stand in all parts. On examination of some roots the treated plants had root nodules and the untreated were barren.

Eminence. R. R. Geltner.—I succeeded in getting an excellent stand of alfalfa. Former trials proved a failure where not inoculated. Believe the inoculation will be a great success.

Moreland. N. J. Cone.—Cut alfalfa first year. I inoculated 1 bushel of alfalfa seed and sowed one-half bushel without inoculating. Got very fine stand of that inoculated, not so good on that which was not.

Maine, *Seal Harbor.* Ida M. Bodman.—The inoculated seed produced a good though not luxuriant crop; the uninoculated seed (or, rather, piece of ground) was more buckwheat weed than alfalfa. My soil is poor, thin, and shallow.

Wayne. S. H. J. Berry.—Last year I tried to raise alfalfa but was unable to get a stand, but this year, by the use of the inoculation, I have a very pretty plot of this valuable grass. I believe it to be what my land requires.

Maryland, *McDaniel.* William Bielefeldt.—Inclosed please find your card filled out as to general results. I did not harvest any hay off the field, but pastured it lately. I am sorry that I am not able to give you any definite figures on the crop, and as your card is not large enough to express my appreciation and enthusiasm for your method of inoculation you will please excuse this letter, in which I will try to sum up my observations of the experiment in the following: I inoculated 1,800 pounds of alfalfa seed with the material received. I dried the seed well after inoculating and sowed it from May 1 to August 15. The land is a medium heavy fine clay soil and originally, I think, a fairly good soil, but has been entirely farmed to death with continuous tobacco raising, and after that wouldn't grow any more they followed it up with wheat and corn till that failed to grow any more; then the farm was sold. So I can say the soil is in a very poor condition chemically and physically, so much so that on 2 acres sown with seed not inoculated, alfalfa failed to make a stand at all. But on all ground in the same condition the inoculated seed made a brilliant

MARYLAND—Continued.

stand and is looking a real deep green in color, when nearly everything else is dried up, as we have had no rain for six or seven weeks. In all, allow me to say that in my opinion your Bureau has made the greatest discovery toward helping the growing of alfalfa that could be made, and that you may well be proud of it, and I thank you for giving me a chance to use it. A neighbor adjoining me sowed uninoculated seed three successive times on the same piece of ground and failed to get a stand; that is positive proof of the inoculation being a benefit.

MICHIGAN, *Croton.* E. L. Hornbeck.—I have a nice stand of alfalfa. I think I never before saw young plants push forward as rapidly on the start. The land is sandy but I have a nice young meadow as the results of my applying the bacteria. It was a complete success.

Kiffie. A. L. Rockwell.—Mixed bacteria with soil; sowed broadcast after seeding; harrowed lightly. Seed all grew and made a good stand. Other seed without bacteria failed.

MISSOURI, *Alexandria.* Jasper Blines.—The material is a success. After six weeks I found large bacteria tubercles upon the young alfalfa roots.

Brewer. L. S. Hogan.—Seed sown has plenty of nodules on the roots and promises a good crop next season. The same piece of land sowed to alfalfa in 1902, seed not inoculated, all died out the following summer.

Levy. Thomas O. Hudson.—Planted in 1901. Inoculation good. Alfalfa was sickly and yellow and spindling, and did not do any good till this year after inoculation. This year it has been dark green and thrifty, and I think it will be better next year.

NEBRASKA, *Agee.* Sam Nelson.—Got a good stand and it has made good aftergrowth where twice before it was practically a failure. Am satisfied inoculation gave good results.

Atkinson. H. E. Henderson.—I got a good stand where I had failed twice before. I think it the only safe and sure way to secure a stand.

Liberty. Harry D. Huyck.—I sowed seed and inoculated soil on a 2-acre field of 2-year-old alfalfa to thicken stand. Produced 10 loads of hay as against 5 loads in 1903. All young plants thriving, old plants much better stand, probably due to severe harrowing and inoculation.

Omaha. A. L. Cottrell.—Alfalfa bacteria successful for alfalfa inoculation. Growth larger. Full report of experiment is given in my post-graduate thesis on "Alfalfa as a forage crop for Iowa."

Page. L. M. Butler.—The seed inoculated was more satisfactory in stand and growth than that sown without. Think it is all right.

Utica. John C. Lloyd.—Ranker growth than before treatment and a much heavier crop of hay. Cut three times and could have cut four, but pastured the last crop. The bacteria were used on 5 acres of alfalfa sown three years ago, with above result.

NEW JERSEY, *Rosenhayn.* A. F. Lewis.—This year I have a fine stand on the same ground that I failed on twice without inoculation.

Vineland. E. L. Bolles.—First cutting on May 25, 1904, of 2 to 3 tons from 1 acre (seeded August 25, 1903), nine months from seeding. Scores of trials without inoculation have been made in this section with universal failure. Alfalfa wintered well, while we had a killing winter for crimson clover.

NEW MEXICO, *Nogal.* Ed. C. Pfingsten.—Inoculation applied on seed, no bacteria; soil inoculated shows bacteria on all roots examined. Soil inoculated plants from 20 to 30 inches high, others 6 inches.

NEW YORK, *Fillmore.* C. V. Mills.—It looks very promising to go into winter. It had a good color and never turned yellow during its growth. I can find plenty of nodules. I think the bacteria a benefit. Tried growing it two seasons without, and it made a sickly growth.

Amsterdam. Barlow W. Dunlap.—Sowed April 27, after treating seed and drying, 90 pounds to 3½ acres with 1 bushel of barley per acre. Have cut twice, and now have a very thick even stand of alfalfa about 10 inches high, of a very dark-green color. I have recently examined the plants in all parts of the field and find nodules on nearly every root. The same piece was sown with untreated alfalfa seed in 1902. The plants started well, but nearly all died before fall. I could not then find a single nodule on the roots.

Apalachin. C. L. Yates.—Sowed last year on piece adjoining and had no luck. Plowed the ground this year 1st of May and have got a good stand. Think the inoculation was a good thing.

Briarcliff Manor. Walter W. Law, manager, Briarcliff farms.—Good stand. I never could get any to take before.

Canastota. W. R. Groat.—A grand success. Carefully carried out your instructions in preparing the culture and in inoculating the seed; rolled it in and have a heavy even stand 8 inches high over the entire 3½ acres. Have spent a great deal of time in getting information about what success others have had in these parts, and all complain of not being able to get a good stand, and some sow 1 bushel per acre and then do not get it. This is my first attempt, but I am satisfied that my success is due to the inoculation, but one in preparing must carefully carry out your instructions to insure success.

Stanfordville. Albert Knapp.—This seed was sown on ground where I tried to get alfalfa the year before and failed, the plants turning yellow when about six weeks grown, and dying. I now have a fine stand on same ground, the result, I think, of inoculation.

Waterport. F. C. Broadwell.—Continuous rains prevented seeding in spring as expected. Catch remarkable and growth fine for the time sown (August 22). Benefit of inoculation very noticeable.

Willard. Frank L. Warne, steward, Willard State Hospital.—Beneficial and satisfactory. A portion not inoculated does not show the sturdy and healthy growth that the main portion of the field does. Two crops have been cut, August 10 and September 30, though not seeded until June 16.

Youngstown. Elbert L. Baker.—Nodules seem abundant, and color of plants good throughout the season.

NORTH CAROLINA, *West Raleigh.* C. K. McClelland.—Four cuttings have been made; second and third cuttings contained much alfalfa. Examination shows plenty of tubercles on the roots, so inoculation was successful.

OHIO, *Cincinnati.* Jas. P. Holdt.—A good stand, while another field about same quality of ground not inoculated had a poor stand and was severely affected by the drought. Tried seed inoculation and ground inoculation, and there seemed to be no difference in results.

East Springfield. Jos. D. Flenniken.—On examining the plants July 8, every plant had the nodules formed on the roots. I think it a success. So far I am pleased with result. (Later, November 2.)—I have a good stand of alfalfa and it is at present about 10 inches in height. My neighbor planted some same day I did, with the same attention and same treatment, except he did not inoculate. I was in his field October 28, and his plants were small, puny, sickly things and very scarce. What he had I don't think will winter, while

Ohio—Continued.

the roots had no nodules that I could find. My plants have roots as large as a lead pencil and nodules as large as peas on them and as many as fifteen stools on one crown.

Leesburg. Arthur Ladd.—Date of planting May 12; date of clipping August 1. The inoculated seed was 8 inches high and a dark green color. The uninoculated was 2 to 4 inches high and yellow in color. Uninoculated seems to be dying out.

Malta. C. A. Clements.—Got a stand of thrifty growth and of dark-green color. Think the inoculation successful as there are nodules on the roots. Neighbors say if I can grow alfalfa on that land it can be grown anywhere in the country.

Montpelier. D. W. McGill.—Good stand where none stood without inoculation. Am satisfied inoculation helped.

New Alexandria. A. C. Fellows.—Result of inoculation is good. Alfalfa is dark green, while strip not used on is turning yellow.

Sharon. J. B. Keys.—Have a fine prospect; find splendid nodule formations on the roots.

Yellow Springs. M. R. Grinnell.—Seed came up very quickly and has made wonderful growth; roots have nodules on them very thick. Bushel of seed sown on 2 acres with 1 bushel of oats per acre. Harvested 4½ tons of hay at two cuttings.

Oklahoma, *Lambert.* T. W. Croxton.—Good, a perfect stand, and of healthy color. On upland prairie.

Oregon, *Applegate.* C. H. Elmore.—Seed all grew and lived through a dry summer on high, dry hill land; bids fair for a good crop next year. Without treatment the seed did not germinate at all.

Bedfield. Albert Mark.—We sowed 10 pounds of seed on about three-fourths of an acre. One-half was richly manured, which did not do very well as it mostly went to weeds. The other half made a good stand, grew 18 inches high, and came up very thick, all without water.

Days Creek. C. N. Wood.—Will say I followed the directions and succeeded well. I planted alfalfa seed May 2, 1904, on fairly good clayey loam. Had to cut it twice. The last cutting one-half ton per acre on August 25, 1904, or in four months from date of planting. I sowed red clover the same day and cut the same date and harvested 1 ton per acre in four months from date of planting. This result is with irrigation. My neighbor sowed alfalfa and red clover the same time I did, also with irrigation, equally as good seed and equally as good or better soil, and his crop did not get large enough to clip at all this year yet, and it looks sickly, while mine is thick and a rich green in color. My crop of alfalfa and red clover is at least 60 per cent ahead of my neighbor's. Mine was inoculated and his was not. I shall use soil from the inoculated field to inoculate other fields of the same kind of crop.

Pennsylvania, *Hookstown.* S. M. Ramsey.—A success at the present time. A good stand and good color. The same ground sowed last year was a total failure; came up sickly and yellow and dwindled away.

Hosensack. E. A. Mackling.—The stand was much thicker than that from seed planted on the same ground the year previous.

Muddycreek Forks. Vallie Hawkins.—Sowed 3 acres without inoculation last year. Good stand but few nodules. Had to resow this year (August 2), and inoculated seed. Roots are well supplied with nodules and I have a good stand, 8 to 12 inches high, on October 18.

PENNSYLVANIA—Continued.

Tyrone. H. C. Blair.—Alfalfa tried last year (1903) did not grow. Inoculated seed produced a good stand. Last measurement of a stock showed plant 12 inches high, root 4 inches. We consider the results fine.

SOUTH CAROLINA, *Williamston.* A. W. Attaway.—Very dry time on it, nevertheless a very good stand. Think inoculation very profitable. Others tried without inoculation and fell behind me.

TENNESSEE, *Clarksville.* Gold Goodlett.—You sent me a package last year, but the weather turned so cold that I did not sow seed; kept all until spring, treated seed, and secured a wonderful stand; think every seed came up. I mowed it three times.

Columbia. Horace B. Hanson.—It has tubercles formed on the roots; is looking fine and healthy. Some of it is on very thin land. I have been trying this plant on the same land for three years without success.

TEXAS, *Fort Worth.* W. H. Irwin.—Sowed 1,000 pounds of seed on 50 acres. Obtained one-third more alfalfa hay where inoculated; three-fourths ton per acre first cutting, 1 ton each other two cuttings.

San Antonio. B. G. Barnes.—The inoculated appears to be more vigorous and healthy than that without inoculation, although the latter was planted first and originally came to a better stand by reason of the ground being in good condition at the time of planting, while the inoculated was not.

VERMONT, *Randolph.* John W. Burt.—We think the result is very good. If we had cut as a crop this season we would have gotten a good yield, and we are confident that next year will show satisfactory results.

VIRGINIA, *East Leake.* A. K. Leake.—It is 18 inches high and could not be more promising; looks splendidly. You will see by the samples I send you that it is full of nodules, showing in an astonishing manner the bacteria-bearing nodules. There are nodules on every plant I dug up. When I dug up some old plants from a field which has failed, I saw no nodules. No one has ever succeeded with alfalfa here.

Ettrick. W. S. Ivey.—On land sown dry, splendid results; plants 8 inches tall and well spread; on wet land, poor results. Bacteria nodules plentiful on most of plot larger than grains of wheat.

Glenallen. Mrs. Imogen Holladay.—A very good stand. I have been unable to get one without inoculation. The roots are plentifully supplied with nodules.

Norfolk. Dr. Livius Lankford.—A most decided difference between inoculated and uninoculated 4 acres; 4 to 6 inches high (6 weeks old), deep green all over. One acre not inoculated nine-tenths dead, rest yellow.

Occoquan. W. W. Giles.—I sowed the inoculated alfalfa seed May 24, 24 pounds to the acre, with a wheat drill, sowing slaked lime at same time and in direct contact with the seed. It came up splendidly, and, I believe, too thick. Thirty days after it was sowed it was 6 inches high, and is now looking elegant. Twelve years ago I sowed 2 acres of alfalfa here and never discovered a spear of it growing. Of course, this was before the inoculation was known. (See Plate IX.)

WASHINGTON, *Belma.* Chas. Richey.—Inoculation very beneficial. Growth had formerly been very poor; plants turned yellow and many died, making it hard to get a good stand. Now difficulty is overcome.

Cheney. Roswell K. Johnson.—My experiment seems to be successful. We have the nodules on the inoculated plants, but none on those not inoculated. I think there is an improvement in the growth of the inoculated plants.

WASHINGTON—Continued.

North Yakima. W. J. Hess.—Fourth year. The crop, which had been short, pale, and spindling, took on a darker color after inoculation and made a rank growth. Yielded, I think, about three times as much as formerly; did not weigh.

Sprague. Arthur A. Baldwin.—Results very satisfactory. Yielded about 1 ton per acre on dry hill land. Good prospects for next year. Has had positively no rain since last of May. (Report dated October 9.)

Winona. W. H. Mumford.—Inoculation appeared to be perfect, all plants having good color from the first, and at no time have there been any yellow leaves.

WEST VIRGINIA, *Berea.* John E. Meredith.—Have been trying to grow alfalfa twelve years, and have now the finest prospect of success that I have yet experienced.

WISCONSIN, *Fort Atkinson.* "Hoard's Dairyman," November 11, 1904.—An experimental trial of this method of inoculation was made by Professor Short, one of the editors of this paper, last summer with very evident success. Our field already shows the good effect of inoculation. (The method consisted in going over an alfalfa field which was not thriving with a sprinkling cart containing the culture liquid. The operation was comparatively inexpensive, as a 16-foot pipe drilled full of holes was attached to the rear of the sprinkling cart, the water thus taking a sweep of nearly a rod in width.)

Stevens Point. F. G. Pattee.—Where treated, found some roots with clumps of nodules as large as small hickory nuts; where not treated, only an occasional one.

RED CLOVER.

CALIFORNIA, *Arcata.* William W. Turner.—A part of the ground was a loose sand, a deposit from the river. It was a hard matter to get anything to grow on it. Here is where my inoculated clover seed seems to grow and flourish. The rest of the ground was a sediment loam and very rich. It was not long before the pigweed started, and it came so thick that it choked out the clover, except what was on the sand. That is growing nicely; has a nice dark-green color.

CONNECTICUT, *Bethel.* George H. Pearson.—Clover made strong growth before rye was ripe. Cut one ton of red clover the middle of September, after rye was cut. Poor sand and gravelly knolls did nearly as well.

Wolcott. Samuel Wilson.—I sowed about 8 pounds of seed, not inoculated, all over field and 3 pounds of inoculated seed in the form of a cross. Result, cross distinct with clover; balance of field none. In company with Mr. E. R. Bennett, of Storrs Agricultural College, I went over fields about September 1 and found stand of clover apparently increased since harvesting.

DELAWARE, *Townsend.* J. H. Lamb.—Sown on ground where clover failed in spring of 1903. Now have a beautiful stand all over the field.

IDAHO, *Cœur d'Alene.* James Reid.—Considerable improvement. On examination, found few nodules on clover uninoculated and very abundant on clover inoculated.

Dupont. J. H. Coon, sr.—Seed was sown on a plot 6 by 7 feet, and has made a good stand about 10 inches high. I sowed a similar plot with same seed not inoculated, and can not find a single plant on it.

ILLINOIS, *Anna.* J. W. Fuller.—Splendid. Got good crop where I had failed eight years in succession.

Emington. C. H. Gilbert.—A more vigorous growth than where seeds were not treated. Made a good growth where I could not raise clover in former trials.

Illinois—Continued.

Neoga. C. L. Wallace.—Seed treated with bacteria was seeded on extra thin land and secured very good stand.

Rantoul. Karl Ekblaw.—As the clover was plowed up, no accurate estimate of benefit could be calculated, but the stand of clover was at least 25 per cent better upon inoculated ground.

Winslow. J. H. Benfer.—Used inoculating material and the clover roots have the little nodules on them all right. Other fields, not inoculated, have no signs of nodules.

Indiana, *Colfax.* T. C. Holloway.—The clover was pastured after the crop of wheat was taken off. Can give no exact figures. It was sown on white-clay land that has been producing very poorly. It now seems equally as good as that on the black land.

Iowa, *Muscatine.* Charles A. Price.—Clover sowed with oats. The oats showed an increase of 15 bushels per acre over oats on same ground where no treatment was given. An examination of the clover roots showed 75 per cent more nodule formation than on that from untreated seed.

Shellrock. John McNamara.—Good. The land was worn out that the clover was sown on, and clover would not grow there without the inoculating material. I have tried clover on the same ground for the last four years and it would not grow.

Kansas, *Burlington.* John W. Alexander.—Plots 1 and 2, 4 acres each, yielded three-fourths to 1 ton per acre; seeded April 15. Plots 3 and 4, 1 acre each, not inoculated, but seeded at same rate and at same time, very weak; not much growth, no hay cut.

Kansas City. John Porty.—The clover on 5 acres was about 35 per cent better where the seed was inoculated than the other 5 acres where the seed was not inoculated.

Winchester. B. G. Jeffries.—As clover will not do any good in Oklahoma, I was surprised at my success, and think it just the thing for Oklahoma.

Kentucky, *Hopkinsville.* Ben C. Moore.—Cut 2 acres of clover which had been inoculated and 2 which had not been, and find that there is a difference of about 500 pounds per acre in favor of inoculated seed.

Olmstead. John T. Young.—I think the clover will live. Good stand at present (October 26), although we have had the most severe drought since July 15 I ever saw. All other clover sowed at the same time is dead.

Warsaw. E. A. Rea.—Have a good stand, with a prospect of a fine crop next spring. Small plot in middle of field not inoculated all died out.

Maine, *Augusta.* John Jackman.—The very best results. I soaked or moistened seed carefully, as per directions, and reserved small piece of ground for test; rest of ground was sown to same kind of seed, but catch on inoculated patch is noticeably stronger. It seems as if every seed came up and grew.

Portland. W. S. McGeoch.—Increased yield about 20 per cent.

Wayne. S. H. J. Berry.—Have in previous years had very unsatisfactory results in getting a catch of grass, and especially clover. I tried the bacteria for this crop and am well pleased with the results.

Maryland, *Grayton.* Rev. William Brayshaw.—Report on clover sown September, 1903, at Valley Lee, Md. I sowed two lots of seed side by side, one inoculated, the other with 100 pounds of South Carolina rock. Inoculated made double the growth and bade fair to give three times the quantity of hay. (A later report states that the clover was pastured, and no figures as to final yield could be given.)

MARYLAND—Continued.

Smithsburg. S. H. Buhrman.—Set of clover is 50 per cent better at this date than it was one year ago at same date. Never had a finer set of clover. Certainly must give the inoculation the credit for fine stand.

MASSACHUSETTS, *Boston.* Israel Lefavour.—Fully double over that where no inoculating material was used. The increase would have been much larger proportionately on poorer land, I think. I shall try on land next year that has not been fertilized in twenty years.

Concord. Wilfred Wheeler.—The plants were large and very heavy, some growing 3½ feet high. I am satisfied the result was due to inoculation. (Seeded April 20, report August 1; only three months' growth.)

Pittsfield. W. R. Stevens.—Used 8 quarts of seed to the acre with timothy and redtop and have never seen a finer growth of clover. To test the inoculated clover seed on poor soil (or no soil) on a side-hill pasture where to my knowledge it has not been plowed for over 60 years—the soil all washed off and no vegetation growing which stock would eat—I spaded a small piece, sowed clover, laid on brush to protect it from cattle, and the result was a thick, rank growth of clover not only where the ground was spaded but several feet below where heavy rains washed the seed down, thus proving the value and benefit of the microbe inoculation beyond the chance of my doubting.

MICHIGAN, *Fennville.* Chas. E. Bassett.—Inoculated part of field gave 12 per cent more yield, and nodules on roots were as large as small peas, while on that not inoculated the nodules were extremely small.

Manton. Will S. Felton.—The clover on the hills and light spots is fully as good as that on the heavier soil, and the stand is much more even and vigorous than untreated seed on similar soil.

Napoleon. E. L. Griffin.—A glowing success till about June 30, when the crop was killed by excessive drought. One-half acre in protected place a splendid success. On the half acre great numbers of nodules are present, and rank growth of clover.

Royal Oak. H. C. Wilson.—This season has been very unfavorable for clover in this locality. Will say that no one near here has a catch of clover that I know of except myself. Have a good catch of clover on three-fourths of my field of 7 acres. Believe it was because I used clover culture.

MINNESOTA, *Campbell.* N. W. Ware.—Bacteria nodules show in abundance and plants very thrifty. Sown on 15 acres of northwest Minnesota Red River prairie soil with best results. Former owner tried in vain for years to get a stand of clover.

Montevideo. John C. Lucas.—Have an extra good stand, and the finest roots full of nodules of very large size. This clover was grown on land that never had clover on it before.

MISSOURI, *Cabool.* C. L. Morris.—Sowed two plots. Plot 1 was inoculated and has made a fine growth. Plot 2, not inoculated, has nearly all died out. Plot 1 a success; plot 2 a failure.

Chapel. Verona Jones.—I inoculated the soil and I harvested two crops off the ground that was treated. The last crop was well filled with seed. I believe inoculation to be a great help here, as far as I have tried it.

St. Louis. G. S. Myers.—One-third better in growth and appearance than the uninoculated.

Sedalia. Jay H. Decker.—Where seed was treated the stand was nearly twice as heavy. The ground was sown with same seeder, adjusted the same.

NEBRASKA, *Elgin.* Marcus Brown.—Inoculation successful, nodules appearing quite plentiful, though uneven. Crop appears best I ever saw in Nebraska.

NORTH CAROLINA, *Loftis.* Benj. G. Estes.—I have a fine catch of clover where I have not been able to get clover at all. In fact, the farmers say clover will not grow here at all.

Skyland. A. B. Case.—Find at least a gain of one-third more nodule formation over the seed not treated. A success according to my investigation.

NEW YORK, *Adams Basin.* C. O. Barclay.—I never had as good success with clover seed before. It looks as if every seed germinated. I have failed for the past three years.

Albion. Oliver A. Paine.—We had good success with our clover. One-half larger where we used inoculating material.

Butterfly. J. E. Baker.—I have a good stand of clover on ground that I did not expect could grow it successfully. It came up the soonest and rankest in the spring of any I ever grew.

Ghent. George T. Powell.—Sown in orchard for cover crop. On October 15 the inoculated seed stood 4 inches higher than adjoining untreated, while nodule development was greater. The gain is more marked on this poor land than on fertile.

Holland Patent. H. W. Dunlap.—My tenant reports the best stand he has had during his occupancy of the farm, and that upon a hillside where until then he had never been able to make red clover grow. Plants I examined in August showed nodules in every case. Having more of the culture liquid than could be used upon the seed, I distributed this on some light loam, which, after stirring and drying, was broadcasted upon a small part of a field already in clover. My tenant reports that the color and size of the clover indicated the distribution of the soil perfectly.

Prattsburg. B. I. Graves.—The clover where clover inoculation was used was far better than where sowed without. A perfect success. The inoculated ground the poorest; sowed as other seed.

OHIO, *Cincinnati.* C. M. Anthony.—We inoculated our seed, and our clover has made most excellent growth on very poor sandy soil in the fruit district of Michigan.

Seaman. Ira C. Howard.—A fine set on clay upland. I sprinkled the water that was left after soaking the seed over the ground in spots; every spot is plainly visible.

Sidney. Miss Ida K. Wilson.—Perceptible nodules, though not much larger than pin points, but both root and top development much greater than that produced from noninoculated, and the latter produced no nodules. Soil a worn-out clay.

OREGON, *Corvallis.* C. A. Bareinger.—Inoculation apparently good. Plants vigorous. Best stand I ever had—more favorable seasons not excepted. Attribute some of growth to land plaster. I believe the inoculation a success.

Creswell. R. D. Hawley.—Made a fine growth, 12 inches high, and thick. Another piece sowed at the same time on an adjoining field died out. Nearly all the inoculated is all right and a success.

PENNSYLVANIA, *Arthurs.* J. E. Breniman.—The growing clover is thrifty and well rooted. It will do well on poor Pennsylvania soil.

Center Hall. John F. Alexander.—The result of inoculation has been very satisfactory, having fully twice the growth as compared to seed sown sooner without inoculation. I am favorably impressed with this system of fertilizing.

Pennsylvania—Continued.

Freeport. George T. Ralston.—Have secured a good stand of clover on an old worn-out field that I had failed to get clover on three times in succession. Regard the treatment as a success.

Southport. F. L. Bray.—Clover looks fine in lot where inoculation was used; scarcely any in lot where no inoculation was used. Both lots with same soil, same methods of cultivation, same nurse crops, and same time of sowing.

Tennessee, *Gruelti.* Ig. Schlageter.—Inoculation satisfactory, twice as much as on the side not inoculated. Did not harvest it this the first year, but it was twice as large as the uninoculated.

Vermont, *Berlin.* William McCarthy.—Appears to be good; clover is better where inoculated than any other place in the field.

Virginia, *Flatridge.* J. W. Perkins.—The clover is two or three times larger than portion of field not treated. Can tell where inoculated as far as you can see the field.

Meadows of Dan. Ira J. McGrady.—Inoculation good; the roots of plants are covered with nitrogen traps. Some plants contain as many as 100 nodules to the plant. I have a good stand on land that had been cropped twenty years and never sown to grass.

Sandidges. W. S. Gill.—Seed inoculated produced clover 18 to 20 inches high at this time and blooming. That not inoculated 6 to 8 inches high and sickly looking; not blooming. I have all confidence in the bug and believe it will restore clover to us again.

Wolftrap. E. W. Armistead.—Put the bacteria on 2 acres and then sowed the seed. I got the finest stand I ever saw and a foot high by July 1. (Sowed in March.)

Washington, *Bothell.* Harry G. Brower.—Mixed the material according to directions and thoroughly wet 10 pounds of red clover seed three times and dried each time. What liquid I had left I mixed with 25 pounds of dry dirt and sowed this on 1 acre; harrowed three times. Season was very dry, but the seed lived through and the ground has a good stand. In fact, I am the only one who has a good stand. People told me the soil was too poor for anything.

Marcus. I. T. Peterson.—More than doubled the yield of the clover. Seed was all sown on a uniform soil, and at the same time, side by side, inoculated and not inoculated.

West Virginia, *Elkins.* John B. White.—Inoculation good. Moistened 6 gallons of clover seed with the inoculating material, sowed with oats on 5 acres. Nodule formation on clover roots very good. Very good stand of clover on ground. Have sowed clover on same ground previously with poor results.

Wisconsin, *Iron River.* Joseph Yerden.—I had sowed clover on same land two years in succession and could not get a catch. I used the inoculating bacteria that you sent me and have a fine stand of clover.

Nova Scotia, *Halifax.* Arthur P. Silver.—The clover has grown remarkably strong. The roots are full of little white nodules, which appear to be absent in roots dug up in other parts of farm. Soil was a run-out pasture.

COWPEAS.

ALABAMA, *Fruitdale.* George W. Dibble.—For two years previous to this year I had sown this land to cowpeas. The stand each year stood about 12 inches high. I was not able to find any nodules on the roots. This year with the inoculated seed on the same ground the peas were about 3 feet high, and the roots were covered with nodules from the size of a pin head to that of a pea. I am well pleased with the result.

Muscadine. C. H. Koentz.—Healthier growth of vines and increase of seed pods of from 15 to 25 per cent. The effect of inoculation was plainly visible on poor soil, but on more fertile soil the difference was very slight.

Pineapple. F. I. Walthall.—Increased crop one-third, notwithstanding protracted drought and lack of proper cultivation.

Stockdale. J. L. Stockdale.—Increase of yield about 200 per cent. A very good crop of pea-vine hay.

FLORIDA, *Avonpark.* John Lancashire.—Result of inoculation good. Ground thickly covered with running vines from 10 to 12 feet long. Did not harvest; want to improve soil. Could not get any crop for two years previous.

De Land. A. Cosner.—Inoculation good. Cut for hay; produced double the amount of those not inoculated.

Hanson. O. C. Gramling.—Peas came up; two-thirds stand made moderate vine and leaf and fruited fairly well. Drought cut the crop one-half, though I gathered at the rate of 5 bushels per acre on land that would not yield one bushel per acre last year.

Jacksonville. Millard F. Webster.—A strong bush and heavy yield of peas on part of field inoculated; not enough peas to pay to harvest on part of field not treated. Have planted peas on same land twice before; each time a very small crop.

Pensacola. Geo. W. Howes.—Result of inoculation good. I planted as a fertilizer on poor sandy black-jack land and got a third better results without manure, but inoculated, than on the same land with cotton-seed meal as a fertilizer.

West Palmbeach. G. W. Idner.—On part of land more than 100 per cent difference; on other dry land, 50 per cent. There is no doubt but it will pay all planters to use the culture.

GEORGIA, *Athens.* H. B. Mitchell.—Increase of seed fourfold. Vines were small, owing to severe drought extending from middle of August to November 2. It paid well. Will want more next spring.

Bluffton. P. H. Thompson.—Inoculation of peas with bacteria sent to me, and others at my request, was quite satisfactory. Yield nearly double that of cowpeas planted under same conditions without inoculation.

Columbus. C. B. Gibson.—A fair crop without fertilizer on land that did not grow weeds 10 inches high. Peas not inoculated did nothing.

Covington. John A. Porter.—The peas were planted in drills and on sandy land, and until the drought they showed a marked improvement over adjoining land with 150 pounds acid to the acre. The severe drought in this section has made any other comparison impossible.

Macon. A. F. Jones.—Mixed the culture with dirt and put in the furrow with the seed. The land was very poor and we did not use any other fertilizer. The yield was three or four times as large where the bacteria were used.

Georgia—Continued.

Rome. Hamilton Yancey.—The growth has been rank, of rich dark color over the entire field that was seeded. A difference in favor of the inoculated pea was quite noticeable. My neighbors and friends who have seen the field insist that the field is seeded with a different kind of pea. I wish to express to you my satisfaction and gratification with the experiment. I believe the work you are doing is of inestimable value to the farmers of our country in the future redemption and improvement of our lands.

Stilson. L. P. Garrick.—Planted on rich land, no good was perceptible; planted on rather poor, sandy land, the result was yield trebled.

Stone Mountain. Arthur B. Kellogg.—It is with pleasure that I can report a marvelous growth of the cowpeas which I inoculated with your bacteria last spring. The comparison between the inoculated and uninoculated peas is most pronounced, I should say a difference of 50 per cent.

Illinois, *Mount Vernon.* E. M. Dana.—Sowed in orchard. Each alternate space inoculated shows a great difference in rankness of growth over uninoculated, especially on yellow soil badly worn.

Indiana, *Milan.* James Tribbey.—Cut for hay. Estimated difference between inoculated and uninoculated 300 per cent in amount of vines, hay, etc., in favor of inoculated. No difference in amount of peas.

Willoughby. Louis A. Russell.—A great deal more vigorous growth and healthier vines, with heavier and better stand.

Kansas, *Walnut.* H. C. Coesten.—Inoculation was perfect and satisfactory. Would prefer this method of inoculation to the sowing of soil from field to field; by the latter a person is liable to transfer plant disease. I transplanted the leaf blight to my field a few years ago by doing so.

Kentucky, *Logansport.* R. M. Humphreys.—Two plots same size, same amount of seed sown, with same conditions all round, and the inoculated plot had fine nodules, while the other, that was not inoculated, had but few.

Newton. C. H. Hatchett.—I had a fine yield of pods upon ground that had not grown good crops for many years, and yield of vines was also good.

Winchester. Dr. M. S. Browne.—Estimated weight of hay increased threefold or more; peas fully as much increased.

Louisiana, *Cades.* C. E. Smedes.—Increased the nodules 75 per cent more than peas planted next to them, and vines were more luxuriant.

Lafayette. Ray Fiero.—In 1903 I sowed peas on a side hill and the peas did not grow over 8 inches high, with very small nodules. This year the inoculated peas sown under same conditions made a growth at least four times as great.

St. Martinville. George Lind.—Cowpeas grew well, forming nodules in plenty. I consider the inoculation a success.

Maryland, *Chaptico.* William H. Gardiner.—The 2 acres inoculated grew twice as large, as peas were more prolific than uninoculated part. In fact, the 2 acres were the only part harvested. The rest of thc field was insignificant.

Missouri, *Marionville.* U. L. Coleman.—Where inoculation was used the peas did a great deal better and produced fully one-third more. I found few nodules where the inoculation was not used, but where inoculation was used the roots were literally hanging full of nodules, some as large as peas. I showed samples to several of our farmers, and they all stated they had never before seen as many nodules on one vine.

MISSOURI—Continued.

Princeton. Philip C. McDonald, jr.—Produced about as much again hay with the inoculated cowpeas as with those not inoculated. A very large development of nodules on the roots.

NEW JERSEY, *Metuchen.* Frank M. Moore.—Inoculated peas grew rapidly; large leaves and heavy. Uninoculated check rows were decidedly poorer in growth and texture.

NEW YORK, *Stanfordville.* Albert Knapp.—This seed was sown in drills on worn-out land that has been producing very little for a number of years. I had a very fine growth of vines, with plenty of nodules on roots.

NORTH CAROLINA, *Asheville.* Fred Kent.—Inoculation very good. Am only a book farmer; can not give exact figures. Farmers in the neighborhood wish to know how such peas were grown, as theirs were failures.

Lawndale. F. Y. Hicks.—Rank growth 2½ feet high on land that did not make peas before. Well pleased with the result.

OKLAHOMA, *Crescent.* C. B. Fail.—The inoculation was perfect. The crop of peas and hay was about double that that was not treated. Am well pleased with results obtained.

Crescent. A. W. Sanderson.—Seed was planted on level and given only one cultivation. Result was an enormous growth of vines and about 50 per cent increase in grain over same crop and cultivation last year. Think the nodule formation will greatly help soil.

McCloud. Jesse Hearn.—Rapid growth; quick development; 20 per cent increase in yield. Roots full of nodules. Land in fine shape for next crop.

PENNSYLVANIA, *Hartstown.* J. T. Campbell.—Where soil was inoculated the result was marvelous, four times as great as where there was no inoculation. Nodules one-half inch in diameter.

Manheim. S. R. Nissley.—The plot in cowpeas was just double over the plot that had not been treated.

Wilkinsburg. R. G. Atkinson.—Season very unfavorable, yet the inoculated seed came to nearly a perfect stand, more robust and quicker growth. The difference was quite marked. The method is evidently a success.

SOUTH CAROLINA, *Aiken.* Miss Louise P. Ford.—On 1 acre we planted cowpeas broadcast. On one half of this acre we planted one-half bushel of inoculated cowpeas, on the other half acre we planted one-half bushel of uninoculated cowpeas, plowing them both in just the same way. About the middle of June, when harvested, we gathered 1,375 pounds of hay from the inoculated half acre; from the uninoculated half acre we gathered 750 pounds. The land is known as poor sandy soil, and we did not enrich. This is the result of Miss Pellew's and my experiment on Twin Flower farm. (A fuller account of the above experiment appeared in the Aiken (S. C.) Recorder of October 6, 1904.)

Aiken. G. L. Toole.—The land selected for planting was very poor sandy land. The crop has not been harvested yet (October 10). Peas planted on the same land last year failed to make any peas at all. The peas this year, after being treated with bacteria, are very fine. They grew off like they had been highly manured, but were not. The yield will be increased fully 75 per cent. The vines are full of ripe peas. They bore well in spite of the long drought.

South Carolina—Continued.

Albion. J. E. Stevenson.—Yield of peas increased about 100 per cent. Number of tubercles on roots considerably increased.

Columbia. Ralph Osborn.—Sown broadcast for hay. Cut and hauled in 8 tons of cured hay off the 4 acres. The tubercles were plentiful and large, very satisfactory. That sown May 30 made as good hay as quick as that sown earlier. Everyone who saw it said it was the best piece of cowpeas they had seen about here.

Orangeburg. F. M. Rast.—I tried the inoculated by side of stable compost and will say that it was just as good as those fertilized with compost. I am well pleased with results.

Sandyrun. Charles G. Sonntag.—Increase 30 per cent, nodules prominent, vine growth doubled. Planted on sandy loam and clay subsoil, 6 acres; 2 acres not inoculated, no signs of nodules on them.

Sharon. W. T. Feemster.—I harvested twice the amount of peas that I had ever harvested on the same land. I should like to try more of it next year.

Troy. H. B. Blakely.—Inoculated vines weighed three times as much as those treated the same way on same soil not inoculated. Results interested many of our people.

Tennessee, *Grandview.* M. L. Abbott.—Owing to circumstances crop was not saved for fodder, but those who were familiar with ground estimated it double, both peas and fodder, that on same ground in former years. Roots loaded with nitrogenous matter as never before.

Ripley. M. M. Lindsay.—Five times as much vine and leaves and two times as much peas as planted on same land without inoculation. There can be absolutely no doubt that above results are due to inoculating seed.

Texas, *Bryan.* J. Webb Howell.—Increased yield fully 33⅓ per cent. I believe inoculation is a good thing.

Morales. T. J. Nolen.—A probable increase of 10 per cent over noninoculated seed. Owing to harvesting with swine, I can not be exact about results.

Virginia, *Ashland.* J. P. Wightman.—Seed inoculated very fine; balance of growth small. Nodules very large and in great numbers. Season very unfavorable for peas.

Cedon. Robt. B. Taylor.—I planted the peas in rows 3 feet apart, cultivated them twice, and I found very decided benefit. I left out two long rows without inoculation, and the results could be plainly seen all through the season and also at harvest; a revolution and a revelation.

Danville. T. L. Smith.—The pea vines were the finest I ever saw. I measured some vines 12 to 15 feet long. I made three times as much hay to the same quantity of seed as I ever made. I am pleased.

Ionia. R. Dewsbury.—Had peas on same ground as last year; were more than twice as good and no help given. Last year had no nodules, this year had. Something increased the yield of peas and vines 100 per cent.

Petersburg. Duncan Wright.—Very satisfactory. Am unable to state exact amount of increase; think gain of one-third. Had peas on same land last year when there was no nodule formation on roots; this year on almost all.

Greenbay. Delbert Haase.—Forty-five per cent better in the amount of nodules in test of separate fields. I was well pleased with the result.

Simplicity. Mrs. Rose Fisher.—All the roots simply loaded with nodules. A piece of cowpeas on an adjoining field, not treated, had about one-half as many.

GARDEN PEAS.

California, *Mesa Grande.* Morgan R. Watkins.—The peas were planted in the poorest soil, scarcely good enough for grapevines, little rain fell, as the year was a dry one. The vines were not more than 1 foot high, yet I gathered an abundance of the sweetest, tenderest pods. Peas not inoculated amounted to nothing. The same results were noted in the black-eyed peas.

Nellie. T. O. Bailey.—Result of inoculation good, 100 per cent better than those not inoculated. Crop was used green.

Florida, *Saint Petersburg.* S. S. Stults.—Most excellent. Compared with what we usually get from same soil and same treatment, I got four times as many peas as we do without the microbes.

Illinois, *Tamaroa.* W. J. Appel.—Owing to the wet weather this spring, could not get seed in as early as I would have liked to do, but result was very satisfactory and increased crop by about 40 per cent over the same ground where bacteria was not used.

Wichert. P. A. Bonvallet.—A complete success; crop about doubled on ground where peas were never planted before.

Maine, *Lincoln Center.* C. A. Brown.—Crop about double what I got on seed not inoculated. The stuff is worth a good deal for peas on my soil.

Mount Vernon. Thos. S. Hawkins.—The crop of peas was better than usual, but the effect was not so marked as in the case of the beans; the latter was phenomenal.

Massachusetts, *Boston.* Jesse M. Gore. The pods were larger, fuller, sweeter, and two weeks earlier than peas planted at the same time and under similar conditions with the exception of the inoculation.

Canton. A. L. Mayo.—I can only say that the farmer says the peas treated with the solution overtook in growth the planting three weeks in advance, and both crops were ready for use at the same time.

Florence. Frank H. Graves.—Picked 43 quarts of green peas in the pod. Vines grew from 7 to 9 feet high, and continued in bearing for nearly one month. Very successful. Remarkable growth of vines and heavy crop of pods.

Sandwich. George H. Credeford.—Planted two double rows about 1 rod long; gathered three times enough for a family of four, in all about 1½ pecks. From same soil and amount of seed gathered only about one-half peck last year without inoculation.

Michigan, *Pellston.* H. L. Millspaugh.—We planted four rows of each seed each way; that is, four using inoculation and four without it, harvesting the peas as a green table crop. The results were very flattering to the use of the inoculating material—fully double yield.

New Hampshire, *Franconia.* L. F. Noble.—There were bacteria bulbs everywhere more than an inch through. It was wonderful and it filled me with hope for the future.

New Jersey, *Chatham.* W. H. Meyer.—Seed germinated somewhat sooner than those uninoculated. I recommend it to anyone to use in place of bone dust.

New York, *Clay.* Mrs. Arthur Hall.—Entirely successful. Yield wonderful. Culture applied to earth and sprinkled along pea rows. The soil now seems like sandy loam, whereas it was the heaviest of clay before. Celery following peas is very fine.

NEW YORK—Continued.

Kingston. Mrs. Clara N. Reed.—Three crops from one set of vines, each crop very full and almost double usual crop in quantity. The inoculation has made worn-out soil very productive.

Northwood. John R. Spears.—The tall vine (3 feet high) was cut from a row that was treated with the culture of nitrogen-gathering germs. This sample fairly represents the growth of all the rows thus treated. The short vine (14 inches high) was cut from the row of vines not treated with the culture. It was the best vine among those untreated. The rows were 4 feet apart and the distance between the two plants was about 7 feet. If you recall that the seed was the Dwarf Alaska, the large vine will seem rather remarkable, I think. The nodules are particularly well worth observing. On July 3, I made the first picking from the plot. On 53 untreated vines, taken as they came, I found 102 pods; on 53 treated vines, taken as they came in the next row, I found 856 pods. The first picking well-nigh stripped the untreated row; the treated vines have yielded two good pickings since, and still another is now filling out. Vines first appeared above the ground on May 17, and they had reached a height of from 2 to 3 inches on June 1. The plot was then of uniform appearance as to the thrift of the vines. On June 1, I watered all the vines in the plot, except one row, with a solution or culture of those germs, made according to accompanying directions, and raked fine dry soil over the ground thus moistened. Since that date all the rows have been cultivated enough to keep the surface soil fine and free of weeds and grass, and all have been treated alike in every particular. No fertilizer of any kind has been applied to any of the rows at any time before or since planting. The quality of the soil is uniform throughout the plot. The soil itself could have had no influence in producing the extraordinary difference in vine growth shown herewith. (See Plate X.) If I seem to be burdening you with details, I must urge as an excuse the extraordinary interest excited by the wonderful success attained by the use of the nitrogen-fixing germs.

Scottsville. Frank Kingsbury.—In light sand, soil very poor. The roots were covered with nodules, the vines a good color, the yield good. The nitrogen-fixing bacteria are certainly a success.

PENNSYLVANIA, *Bryn Athyn.* Mrs. J. A. Wells.—On April 14, I planted three kinds of peas. They came up well, but did not grow rapidly. I had inoculated the seed according to directions. On May 14, a neighbor, having obtained a culture for peas, spared some for me. I inoculated more seed and planted them; then having some of the liquid left, I added water at the rate of one-half pint to 2 gallons of water, and having hoed the soil away a little from the roots of the previous planting of peas (now 4 or 5 inches high), I watered them with the diluted culture and hoed the soil back. Well, now the watered planting of peas is a sight—tall, luxuriant plants covered with fine pods. They are the admiration of the neighborhood. The later planting that was inoculated but not watered with the culture is doing better than any peas I have had heretofore, but not nearly so well as the ones that were watered after they were up.

[*Later report.*]—Four bushels of fine, well-filled pods were gathered. Hitherto our soil would not produce peas to amount to anything. My next-door neighbor has soil exactly similar to ours and manured it more heavily. He used the same seed as I did, but my peas were decidedly finer.

Danville. Mrs. G. P. West.—A good crop where heretofore they barely gave seed; good size, a good growth of vine. It is a great thing for the farmer.

PENNSYLVANIA—Continued.

Erie. J. M. Gordon.—Planted a pint of inoculated peas on April 28 in ground that had not been fertilized. At the same time we planted as much more in ground that had been well manured. The crops from each were about equal. After the vines had been pulled up we planted some string beans in the same ground and are now enjoying the result, the vines being as prolific as if they were the first crop of the season.

Philadelphia. Louis Costa.—Result a good third better than other years with same space planted.

Philadelphia. S. N. Lowry.—Vines yielded once and a half the crop yielded by vines from ground not inoculated but which was manured. The vines from inoculated seed yielded full pods and the peas and beans were larger than those from untreated seed.

Titusville. Geo. L. Benton.—I tried it on peas and it was eminently successful. Where I got no peas last year I had an abundant crop after using your bacteria mixture, and I never had such a crop of peas. I think your discovery very valuable, and I thank you for sending the sample to me.

Westchester. Edw. H. Jacob.—Inoculated peas fully matured by October 1; uninoculated did not flower at all. On September 15, 1904, inoculated peas were 18 inches high, uninoculated 8 inches high. Planting was late, but shows big returns by inoculation. (Date of planting, August 15.)

RHODE ISLAND, *Chepachet.* Henry Parsons.—Should think the result of inoculation to be a benefit amounting to about 50 per cent. Can not give result in figures, as the most of the peas were picked green.

SOUTH CAROLINA, *Gaffney.* Jeremiah Gardner.—My peas were better than the peas of others who used commercial fertilizer, ripened early and evenly, circumstances unfavorable. I consider inoculation a boon to agriculture.

SOUTH DAKOTA, *Lead.* A. L. Read.—Sowed on yellow clay. Had great difficulty to loosen the ground enough to cover the seed. Impossible to cultivate. Harvested about 17 gallons of peas of well-filled pods. On piece of ground same size, seed not inoculated, harvested less than one-half gallon of peas.

WASHINGTON, *Juanita.* W. B. Wittenmeyer.—Planted on unfertilized ground. Vines from 2 to 5 feet high and the crop was at least 100 per cent greater than the same kind of pea planted at the same time not inoculated.

White Salmon. W. O. Cox.—Inoculation a great benefit. Crop about double what it would be without it.

WISCONSIN, *Janesville.* J. T. Fitchett.—Plants were stronger, blossomed two weeks earlier, stood dry weather better, and matured more peas than plants not so treated. In addition, I inoculated seed for four other parties, requesting them to report to me. One man reports 50 per cent better yield. His soil was poor, and the bacteria showed more effectively by contrast. A market gardener reports a larger yield than from similar seed not treated; but to him the best feature was earlier maturity by two weeks. All report favorably, those planting on poor soil reporting the largest increase.

Kewaunee. Thos. Zahorik.—Thrashed from 1 bushel of treated seed 19 bushels. From the other peas 1 only thrashed 11 bushels.

Marinette. George R. Hawkins.—They were twice as full as those not inoculated. Sandy loam. Most of them used green. The nodules were very plentiful on roots.

WISCONSIN—Continued.

Sister Bay. Adolph Soderburg.—There were more pods on the vines that were treated. About 3 bushels more peas to the acre on those that were treated than those that were not. There were twice as many nodule formations on roots from the treated seed.

BEANS.

ALABAMA, *Fruitdale.* George W. Dibble.—When the crop was ready for market the beans were picked from both plots. The plot that was inoculated kept growing and bearing fruit; on the other plot they dried up. When the beans were gathered the yield on the inoculated plot was more than double that of the other.

CALIFORNIA, *Nellie.* T. O. Bailey.—Result of inoculation good, 75 per cent better than those not inoculated. Inoculated did not mildew, others did.

COLORADO, *Arvada.* A. B. Cole.—Planted 3 acres adjoining 2 acres uninoculated. The inoculated beans produced one-fifth more to the acre than adjoining.

ILLINOIS, *Chicago.* Stuart S. Crippen.—Yield of beans was one-third above average, and product unexcelled in size and flavor for table use. Seed beans are considerably larger than parent beans.

Rossville. I. A. Smothers.—While I did not plant any untreated seed, I can say that the yield was surprisingly great, a matter of remark by everyone seeing them.

KANSAS, *Ford.* R. L. Wilson.—Result of inoculation decidedly good; ground inoculation did a great deal the best.

MASSACHUSETTS, *Boston.* Edw. W. Greene.—The beans seemed to grow a third faster, to be in condition to use some time earlier, and to give me at least one-fourth more beans.

Cambridge. L. D. Evans.—The beans and peas that I put in early in the summer have grown marvelously well, and in soil that did not seem sufficiently fertile to raise anything but tin cans and rubbish.

Middleboro. Fred A. Orcutt.—I planted the same seed and the same amount upon the same ground with the culture that I did without, and the beans that were treated have done much better in every way than those that were not.

North Falmouth. Ella M. Donkin.—The beans were the admiration of all who saw them, and I invited all whom I could interest in them to see them. I had planted in another part of the same garden beans which, although supplied with fertilizer, did not amount to anything, and I decided to try the bacteria organisms, even if it were late in the season for planting. I planted them July 14, and early in September we had fine string beans to use. The pods were large and of excellent quality. They continued to bear until an early frost killed the vines. * * * We examined the roots in different stages and found the nodules well developed.

Pike. H. E. Howard.—Darker green throughout season without fertilizer than uninoculated with fertilizer. Gave as good results as fertilized portion, ripening about as early.

MICHIGAN, *Brinton.* B. B. Stevens.—Plants more vigorous and better podded. Estimated increase of yield not less than 25 per cent. Am well pleased with the experiment.

Saugatuck. F. M. Kreusch.—I gathered the beans about September 20; have only thrashed part of them, but I am sure I will have five times as many as last year on the same ground. I think it is immense.

NEW HAMPSHIRE, *Penacook.* J. M. Masson.—Beans were exceptionally good—at least 20 per cent over last year on same ground. This increase I attribute to the inoculation.

NEW YORK, *Jasper.* H. W. Smith.—Those inoculated yielded sixtyfold. Those not inoculated yielded about fiftyfold on the same kind of soil with same care. The beans inoculated are one-third larger.

Kingston. Mrs. Clara N. Reed.—Pods very full of large beans. Some vines had a second crop. The inoculation has greatly enriched the soil, so that it is much better to use for other vegetables.

Penn Yan. John D. Buckley.—The ground was on a side hill, gravelly and sandy, and had been practically worked out. In spite of this and insect attacks, I had the best piece of beans I ever raised. A farmer living near me planted beans twice in succession on the same land and I helped harvest the beans, but they were hardly worth the labor.

OHIO, *Linden Heights.* E. B. Champion —Beans yielded fully one-half more than untreated. The green beans carried the largest-sized pods I ever saw, but the yield was not increased so enormously as in the case of the wax beans. In this case the increase was so marked as to cause wonder among my neighbors.

PENNSYLVANIA, *Cresson.* V. P. Sanker.—On ground which never before would raise a crop of beans had marvelous crop this year, the heaviest ever raised in this locality. Planted seven rows in middle of field without inoculating, and the old conditions prevailed.

Lockhaven. George P. Singer.—I used them in my botany and nature-study classes in this way. I furnished each student with a number of pots of fine white sand. The same day they planted beans and clover, and also the same kind of seeds inoculated with the bacteria. Each pot was exposed to the same conditions and the inoculated compared as to growth with the uninoculated. There was no especial difference in germination, but when the plants had put forth their first leaves the ones inoculated began to grow much faster than their neighbors. It was not long until they were twice as high, and while the ordinary seeds produced plants stunted and ill-nourished, the inoculated seeds in many cases produced a large bean stalk with fully developed pods and beans. The clover seed showed the same result. Root nodules were formed in great abundance. All in all, it was the most interesting experiment I have ever tried in my classes, and it aroused a great deal of interest in the students. I am confident that if clover and beans will grow as they did for us in sand which was quite free from organic matter, your nitrogen-fixing bacteria will solve many problems for the intelligent farmer.

Northeast. John Wheeler.—Result of inoculation splendid. Refugee beans for canning factory. One-third acre yielded $50 to $60 clear profit. I think it can not be beat by use of fertilizer.

RHODE ISLAND, *Kingston.* H. J. Wheeler, director, Rhode Island Agricultural Experiment Station.—Concerning the wax beans and green-podded bush beans, both are continuing to show very striking benefits from the use of the inoculating material, so much so that I think it would be a very important matter, economically, if one were growing them on a large scale, whether the land was inoculated or not.

TENNESSEE, *Jefferson City.* J. Porter Corbett.—Difference from one-fourth to one-half in favor of inoculation.

VERMONT, *Middlebury.* J. E. Sperry.—Gain from inoculation 11 bushels per acre over seed not treated, planted side by side. There is no doubt but that it is a great help.

WASHINGTON, *Juanita.* W. B. Wittenmeyer.—Inoculated beans at least 100 per cent better than uninoculated on same soil. Very sandy soil and quite dry this last season.

WISCONSIN, *Marinette.* George R. Hawkins.—Produced fully 100 per cent above those not inoculated. Clean and well-formed; no rust.

SOY BEANS.

ALABAMA, *Rash.* W. W. Lee.—All inoculated but six rows. Inoculated began showing result of inoculation in a few days after they came up, and harvested 50 per cent more than the other.

GEORGIA, *Gainesville.* John E. Miller.—The soy-bean inoculation I got last spring was a complete success. I planted 10 or 12 acres on an old barren field, and they are from 12 to 36 inches high, and have not found a single one that was not inoculated, one with tubercles 26 inches from the base. I think your Department a great help to the farmers.

HAWAII, *Napoopoo.* Gordon Glore.—Inoculation successful. Increased growth of plant and abundance of root nodules.

KENTUCKY, *Winchester.* Dr. M. S. Browne.—Twelve thousand five hundred pounds dried hay, ready for storing, per acre; ground where seeds were not inoculated at rate of 1,500 pounds cured hay per acre. Soil, medium bluegrass sod. Noninoculated a failure; inoculated, wonderful crop. Date of planting, April 15; date of harvesting, July 25.

MARYLAND, *Bynum.* Wilmer P. Hoopes.—Our soy beans, drilled in with corn in rows 3½ feet apart, the whole crop making about 20 tons of silage per acre. The beans just covered the space between rows and yielded at least 2 tons per acre. The roots were just covered with nodules.

Smithsburg. C. M. Leiter.—Growth strong, possibly one-fourth more vine than where not inoculated.

MISSOURI, *Marionville.* U. L. Coleman.—Where inoculation was used the beans did a great deal better and produced full one-third more beans. I found no nodules on the soy beans where not inoculated. The inoculation was a success.

NORTH CAROLINA, *Dome.* D. L. Clements.—The lot of land (1 acre) inoculated doubled in yield of hay the lot not inoculated, side by side in the same field on the same kind of land. The growth where inoculated was very luxuriant.

PENNSYLVANIA, *Guys Mills.* William Miller.—The soy beans made twice the growth of former trials. I think the inoculating made the increased growth.

TENNESSEE, *Spring City.* J. M. Thompson.—Large tubercles covered all the roots, crop of stalks and leaves very heavy gain, 10 bushels per acre. Land poor. I consider the inoculation a perfect success.

VIRGINIA, *Carysbrook.* C. E. Jones.—All of the inoculated hills showed an abundance of nodules, while only a total of four were found on the uninoculated ones, notwithstanding the proximity of the inoculated seed, the roots of both plants often interlacing. One row inoculated by culture and one by soil from soy roots having numerous nodules showed an equal number of nodules; the check had none. I find that the roots show far more nodules than I have ever seen before, and this development seems more excessive on the poorer parts of the field.

Gloucester. R. M. Janney.—I did not weigh the hay, but could see a great improvement over the uninoculated seed from the start, and got double the crop in the harvesting.

Greenbay. Delbert Haase.—Thirty per cent increase in nodules over that which was not so treated by actual test of two fields sown the same week. The crop of the treated was better in color and yield on thin land.

Virginia—Continued.

Ingersoll. Charles C. Deissner.—Although there was only about one-third of a stand on account of poor seed, it made five big loads of elegant hay. The plants were over 3 feet high and loaded with beans. I tried 1 acre without bacteria. They were not near as good, either in growth or in yield of beans.

Ionia. R. Dewsbury.—Had the finest crop of beans I ever raised; rather poor ground without anything to help to enrich. I think the inoculation helped wonderfully. Nodules large.

Simplicity. Henry Fisher.—About 80 per cent of the plants contained from 1 to 20 nodules, almost invariably on the main root. No soy beans had ever been planted on this land before.

Simplicity. Mrs. Rose Fisher.—Nearly all plants had from 1 to 29 large nodules, nearly all located on the taproot about 1 to 2 inches in the ground. An adjoining field, not treated, showed but very few nodules.

HAIRY VETCH.

Alabama, *Tuskegee.* George W. Carver, director, Alabama Agricultural Experiment Station.—The inoculated plot grew vigorously—in fact, made an enormous growth—and made 7 bushels of seed to the acre. The other was so small that I did not thrash it out.

Kentucky, *Trenton.* Phil. E. Bacon.—Used vetch material with best results. The growth was very heavy and the roots as full of nodules as any illustration I have ever seen, some clusters fully as large as the end of my finger.

Mississippi, *Aberdeen.* Isaac H. Hunt.—Inoculated was better in every way than the untreated seed. We are very much encouraged by what we have already seeded.

Missouri, *Rolla.* J. A. Foden.—We have a splendid stand. Color good, and altogether very pleased with result.

Nebraska, *Taylor.* Ray G. Hulburt.—Bloomed three weeks earlier; more seed; larger plants. Oats sowed with it were larger. Roots crowded with tubercles, single and in masses. Sowed too close; germs spread to untreated part in July, but it never caught up. Some plants 10½ feet long.

Nevada, *Skelton.* Jas. H. Campbell.—Best I have ever had. Vetch was so thick I could not see where the machine cut.

North Carolina, *Statesville.* F. T. Meacham.—This vetch grew to a height of 6 feet in some places, although, not having sufficient grain crop to hold it up, it fell over very badly. I think the vetch inoculation a great success.

New York, *Butterfly.* J. E. Baker.—Fine growth on very poor soil. A high, dry, gravelly knoll grew 6 to 8 feet and a mass of blossoms and pods. Have never succeeded in growing anything on this piece before.

Ohio, *Celina.* D. Hellworth.—Nodules are very abundant; simply wonderful. I measured a stalk to-day 7 feet long, besides having four branches.

Washington, *Seattle.* David B. Porter.—Last fall I treated winter vetches with the solution prepared as directed and planted the same broadcast over a small patch of ground with a good deal of clay, some blue and some shot clay. On turning the ground over in the spring, there was a network of roots forming a thick sod about 8 or 10 inches deep and very heavily charged with the nitrogen nodules, some roots having as many as 40 or 50. I have used other rotted vegetable matter with this to form a humus and have now a fine friable soil which yielded very heavily this year.

WISCONSIN, *Germania.* C. E. Pierce.—The benefit was very plain, promoting a rank growth, adding at least one-third to crop.

Meadow Valley. C. H. Johnson.—Inoculation successful. Nodules in quite large clusters on lower fibers of the roots, more scattering near the surface. Planted on high sandy land.

CRIMSON CLOVER.

ALABAMA, *Tuskegee.* George W. Carver, director, Alabama Agricultural Experiment Station.—This was quite noticeable, that on the adjoining plot the stand was just as good as on the inoculated plot, but it grew very poorly. It remained small and yellow throughout the season. The inoculated plot grew fairly well and was very rank and green in color. These plots were treated in every way alike except in the matter of inoculation. One end of the inoculated plot did not get any of the inoculating material and the small inferior clover was very noticeable.

PENNSYLVANIA, *Bellefonte.* James A. B. Miller.—Fair catch on thin soil. About 6 inches high. Failure on same soil last year without inoculation. Seems thrifty and gives every promise of successful catch.

Joanna. H. E. Plank.—It is a satisfaction to inform you that there was a much greater mass of fibrous roots on the plants grown from the seed treated with the material than on the plants from the untreated seed. The nodule formations are much more abundant on the former class of plants. There is a good stand of clover.

WASHINGTON, *Spokane.* Henry M. Richards.—The results heretofore with the same amount of seed have been a very stunted growth and scant blooming. The seed prepared with the inoculating material has produced a most luxuriant growth and a perfect mass of bloom, an improvement so great that it is difficult to describe.

WEST VIRGINIA, *Elm Grove.* George Fox.—Seed inoculated 50 per cent superior to the seed which was not inoculated.

SWEET PEAS.

CALIFORNIA, *Los Angeles.* W. L. Cleveland.—The seeds were treated in accordance with the instructions you sent me, and then planted in the usual manner. The result of this seeding was a hedge of vines that grew to a height of about 8 to 10 feet, covered with a lot of fine large blossoms that were the delight of the whole neighborhood. Across the street, and treated in the ordinary way with the same seed that I furnished them, but without the inoculation, the vines scarcely grew 5 feet and the flowers were small and few. I consider the thing a success.

MASSACHUSETTS, *West Roxbury.* F. G. Floyd.—Plants were very luxuriant and about 12 feet high. Leaves very large and rotund; flowers very large and of fine color. Plants produced several double flowers, i. e., having two or three entire or partially formed standards.

NEW JERSEY, *Newark.* William J. Hesse.—The crop was a complete success, while other growers in this location did not succeed at all. While I have no record of the quantity of the crop, I will say that I had a larger crop, better blooms of lasting quality than any other grower with the same amount of ground planted. I had two awards at the New Jersey Horticultural Society for these same blooms in June and July at Orange, N. J., and I know that had it not been for the inoculating of the seed I would not have been so successful.

FIELD PEAS.

MAINE, *Auburn.* G. L. Thomas.—The product out of No. 1 strip without any fertilizer was as much as out of No. 3 with the heavy manuring. In other words, the inoculating culture had done as much for strip No. 1 as the barnyard dressing had done for No. 3; while No. 2 (inoculated and manured) had produced as much as the other two strips combined. The growth in No. 2 was excessively strong and luxuriant, and this was due to the nitrogen drawn from the air by the vaccinating cultures. No. 1 was fair yield and cost about 60 per cent as much as No. 2 and about 47 per cent of that for No. 3.

PENNSYLVANIA, *Hartstown.* J. T. Campbell.—Where soil was inoculated the result was marvelous—four times as great as where there was no inoculation. Nodules one-half inch in diameter. (See Plate VII.)

TEXAS, *Keene.* A. P. Wesley.—Nodules formed on vines when quite young and the growth was fine, while the land they were planted on was worn-out clay. I think it a success.

WISCONSIN, *Bay City.* Chicker Brothers.—A very satisfactory crop was raised where failure had attended for seven years.

VELVET BEANS.

FLORIDA, *Jacksonville.* E. H. Armstrong.—Thirty to 50 per cent increase over that where seed was not inoculated with the velvet-bean culture; same for cowpea. Season dry, somewhat unfavorable.

LOUISIANA, *Cades.* C. E. Smedes.—Increased the nodules and the vines 30 per cent. Vines were plowed under.

BERSEEM.

CALIFORNIA, *Berkeley.* David Fairchild.—You will be interested to know that at Berkeley this year there was an immense difference between the plots of berseem from treated and untreated seed, the former being several hundred per cent better than the latter.

PEANUTS.

VIRGINIA, *Poplarmount.* Charles Denney.—Inoculated a piece of land according to your instructions, and planted Spanish peanuts. Increased yield at the rate of 5 bushels per acre.

MISCELLANEOUS.

NORTH CAROLINA, *Gibson.* Dr. N. M. McLean.—As to "nodule formation," a test was made by myself in person to determine this feature. Sterile soil (obtained from a sand subsoil several feet below the surface) to which was added a certain amount of phosphoric acid and potash, obtained from acidulated rock and muriate potash, was placed in one-half gallon pots. Each legume tested was planted in a number of these pots. To a certain number a small quantity of the "inoculating material" was added, with others as "control pots." In each test a marked contrast was noticeable in a short time, the inoculated pots showing several times the plant growth the control or uninoculated pots did, and in each case the inoculated pots showed a plentiful supply of nodules on the plant roots. An experiment on a large scale was then tried. A trench 3 feet broad and 12 feet long was dug out 30 inches deep. This was in a heavy clay-loam soil. The trench was filled with this same sterile soil used in the

NORTH CAROLINA—Continued.

> pots fertilized with the phosphoric acid and potash. In each square (3 feet by 3 feet) a legume was planted—alfalfa, crimson clover, soy beans, and velvet beans. Each variety of seed was inoculated with material you so kindly furnished, and in each test there was an abundant "nodule formation." In each one of these several tests the control pots and plots verified the results beyond the possibility of doubt. I hope next season to be in a position to make a tabulated report that may be of use to others. As to myself, I consider your discovery the greatest one of the age and hope you may live to see a universal acknowledgment of the same.

SUMMARY.

Owing to the direct effect of the nodule-forming bacteria upon legumes, these plants are supplied with a source of nitrogen not available to most other plants. Consequently, the legumes can flourish in a soil practically devoid of nitrogen.

The effect of legumes upon succeeding crops of any kind is generally beneficial, because of the fact that the soil is enriched rather than impoverished by these plants.

Where nitrogen-fixing bacteria are lacking, it is possible to introduce them artificially either by transferring soil from an old field where the desired leguminous crop has been successfully grown, or by the use of pure cultures of the proper organism.

The method of transferring soil is objectionable because of the inconvenience and expense, and is apt to be dangerous on account of the possible transfer of weeds, insect pests, and plant diseases.

The use of the German preparation, nitragin, has not been a success, probably owing to the method of growing the bacteria, which reduced their virulence, as well as their being distributed in a form which caused them to deteriorate rapidly and die.

The nodule-forming organism is a true micro-organism, having three well-defined stages consisting (1) of minute motile rods which produce the infection and frequently form zoogl œa masses; (2) larger rods either motile or nonmotile; and (3) capsulated forms, the so-called "branched organisms," which are made up of two or more rods held together in a sheath.

There is but one species of legume organism, *Pseudomonas radicicola* (Beyerinck) Moore. The difference in the infective power of bacteria from different hosts is due to slight physiological variations which can be broken down readily by cultivation.

In order to increase or maintain the virulence of nodule-forming organisms they must be cultivated upon nitrogen-free media. Growth upon rich nitrogenous media tends to diminish and frequently destroys the nitrogen-fixing power, since this element can be obtained more easily from the medium than from the air.

Various external conditions, such as heat, moisture, alkalinity, amount of nitrogen in soil, etc., all have a direct effect upon the legume bacteria, and the failure of nodules to develop may often be traced to such a cause.

The nitrogen is fixed by the bacteria in the nodule and becomes available by the action of the plant in dissolving and absorbing the combined nitrogen in these organisms.

Nodules inhabited by rod forms of bacteria which can not be dissolved by the plant are of no more benefit than any parasitic gall would be.

There is no true symbiosis between the bacteria and the host. The nature of the nodule-forming organism is purely parasitic, and unless the plant can overcome its action causes distinct harm.

It is possible for nitrogen-fixing bacteria to penetrate the roots of plants and be of decided benefit without the formation of nodules or any external evidence of their presence.

While it is desirable that artificial inoculation be made at the time of planting, experience has shown that under certain conditions crops of three or four years' standing are improved by adding bacteria to the soil.

Inoculation is usually of no benefit to soil already containing the proper bacteria, although there may be exceptions. It should not be practiced where the soil is so rich in nitrogen as to prevent the development of the nitrogen-fixing organism.

The inoculation of seed and soil by means of pure cultures grown and distributed according to methods devised by the Department of Agriculture is shown by the reports of practical farmers to be of distinct advantage when used under circumstances that will permit benefit.

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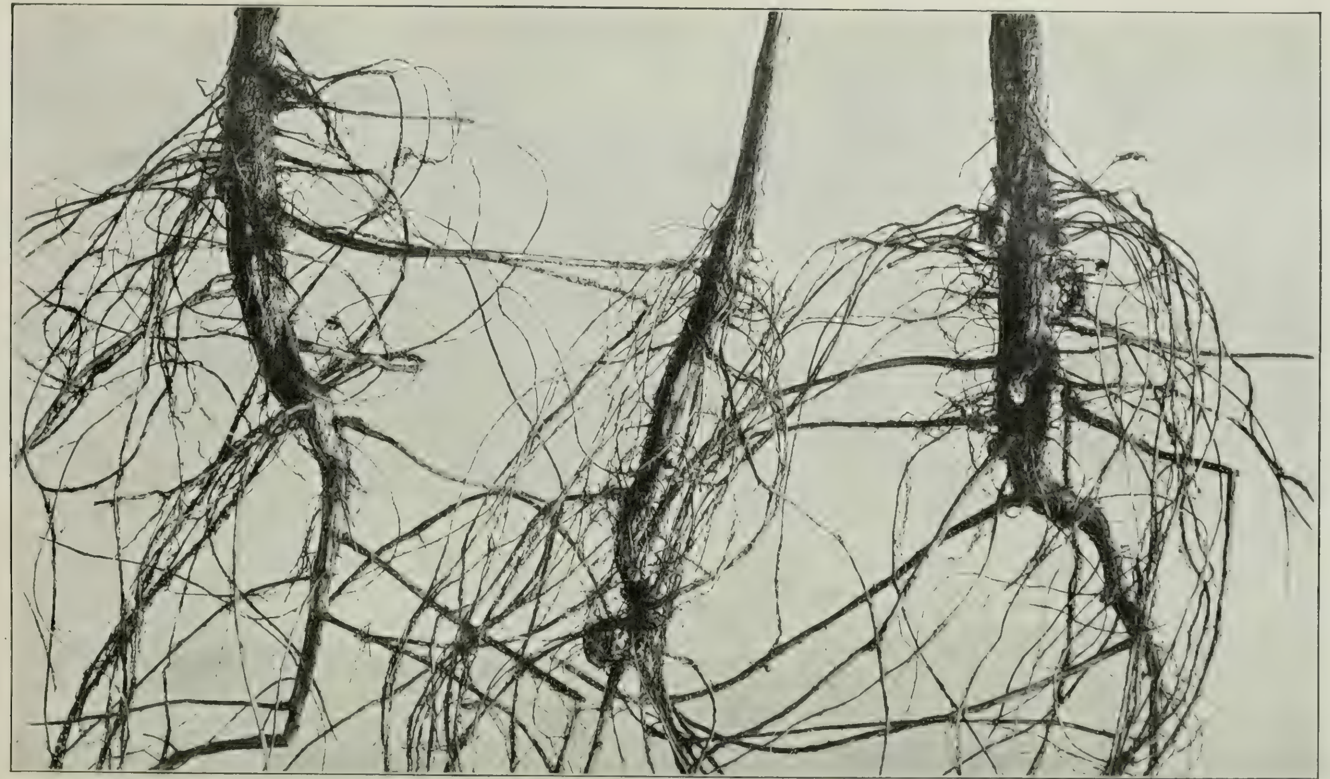
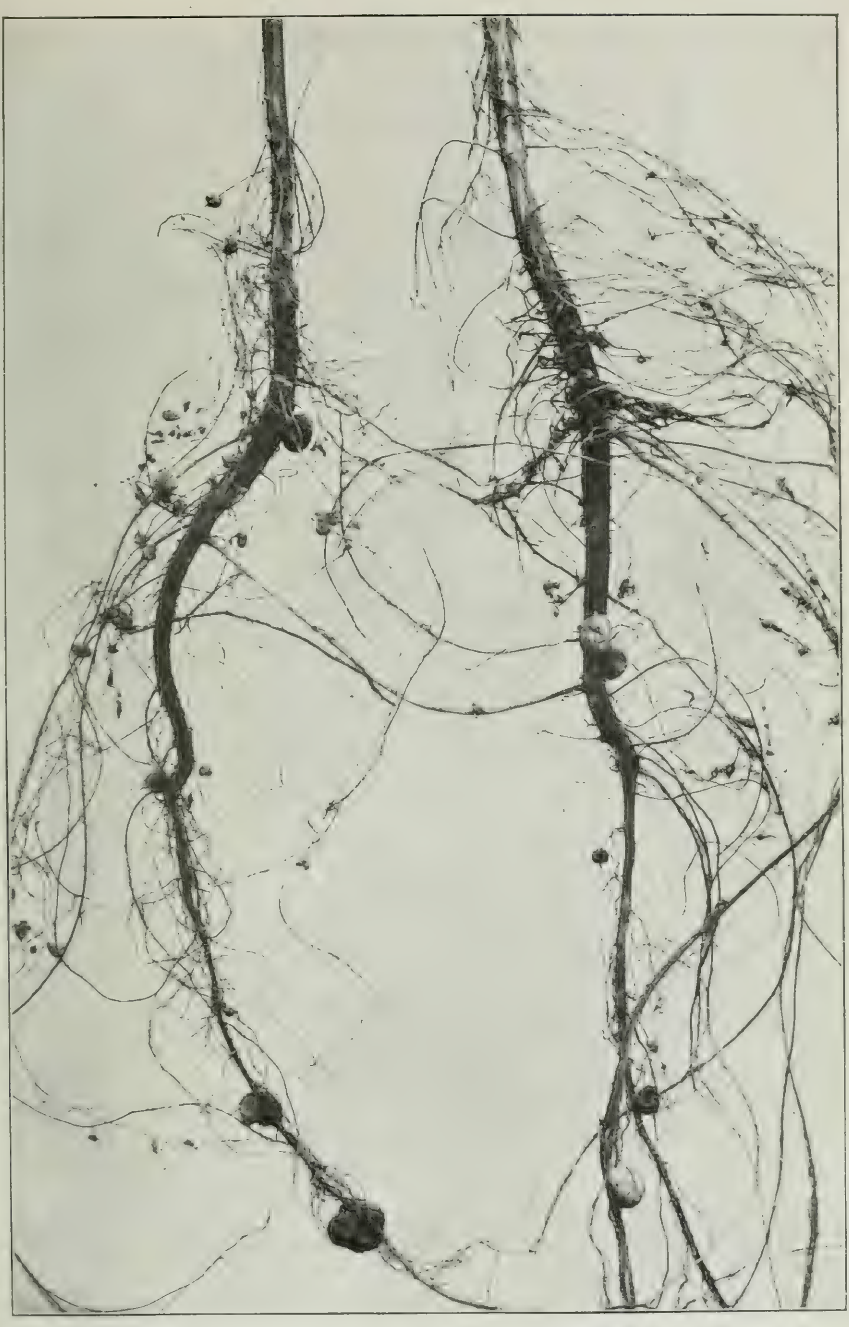


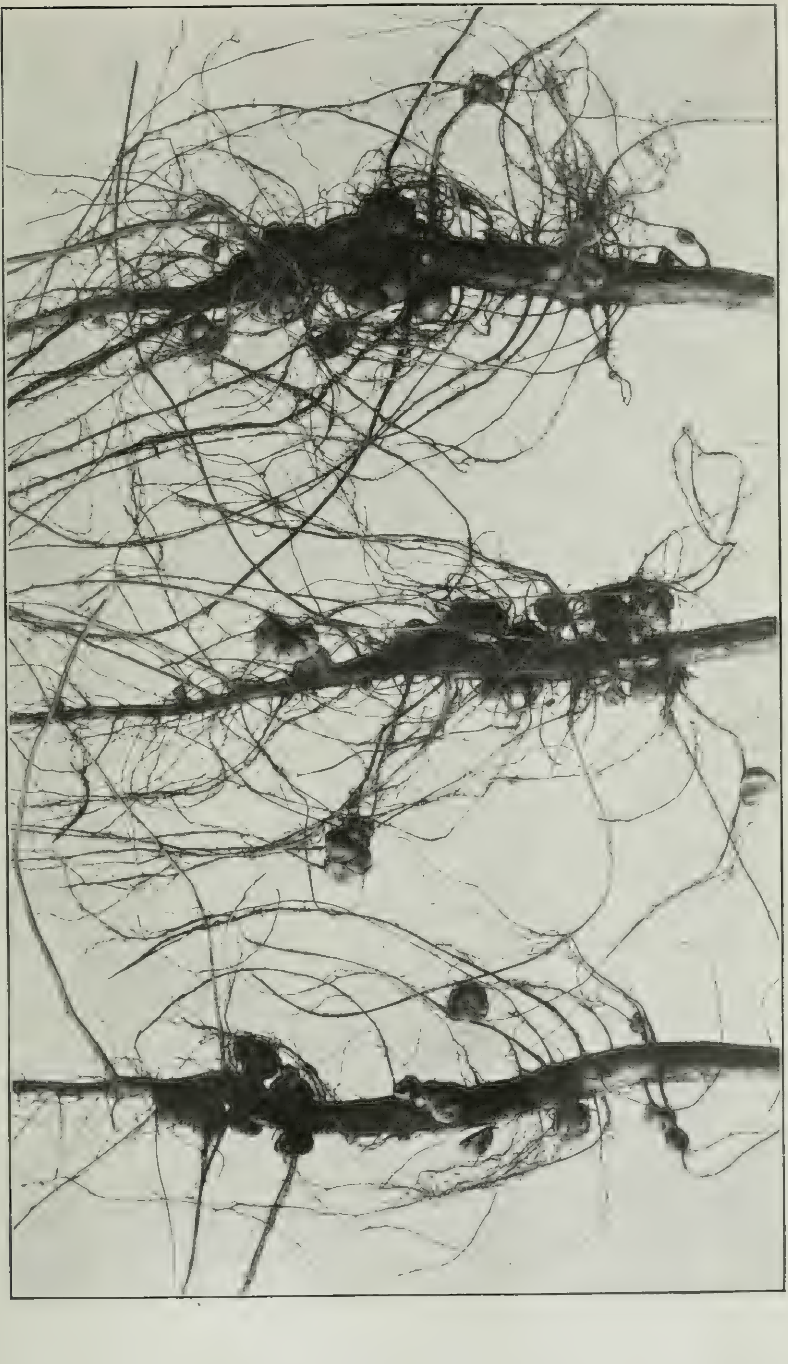
EFFECT OF RICH NITROGENOUS SOIL UPON FORMATION OF NODULES OF SOY BEANS.

Same culture and seed used as in Plates III and IV.



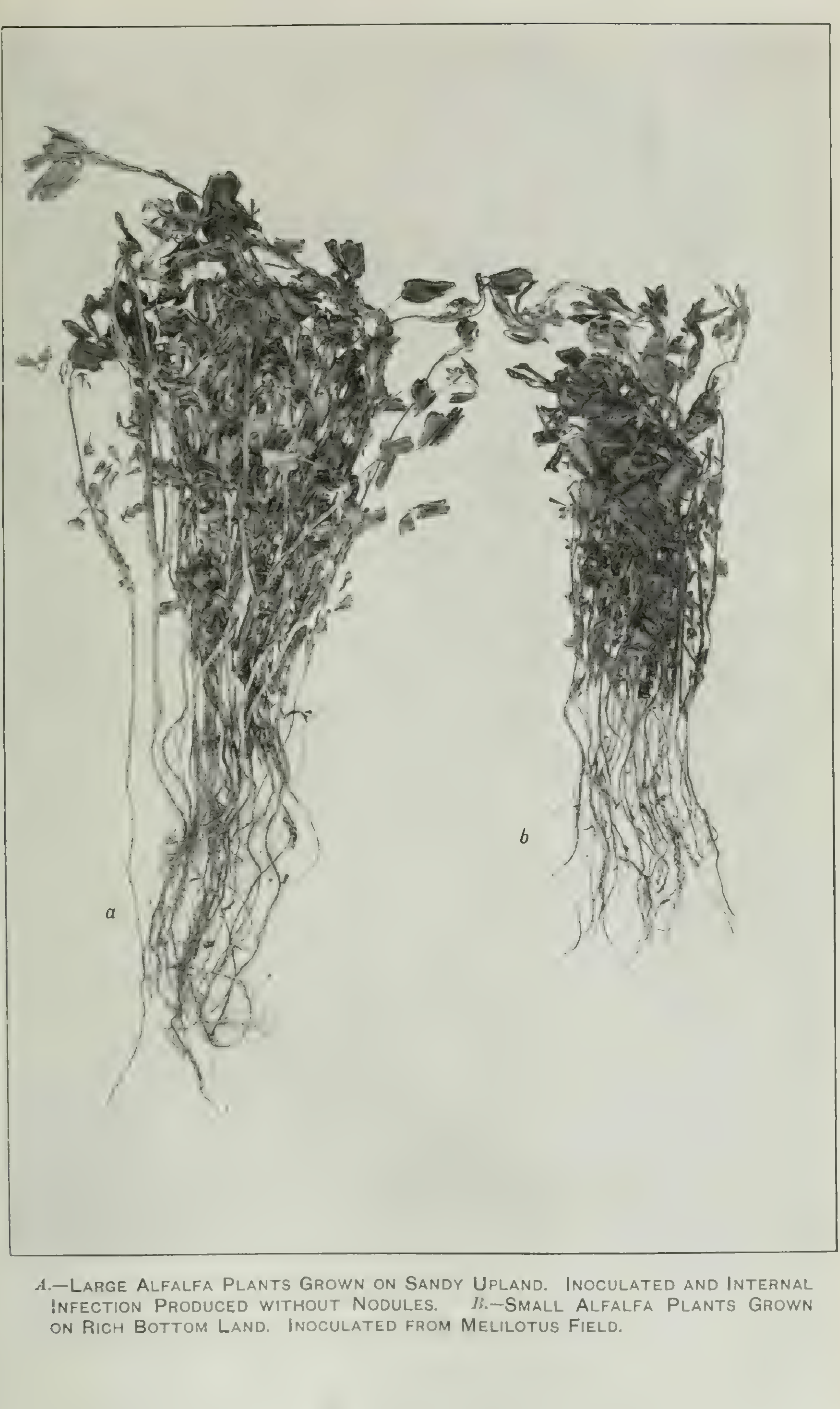
EFFECT OF POOR SANDY SOIL UPON FORMATION OF NODULES OF SOY BEANS.

Same culture and seed used as in Plates II and IV.



EFFECT OF POOR CLAY SOIL UPON FORMATION OF NODULES OF SOY BEANS.

Same culture and seed used as in Plates II and III.



A.—LARGE ALFALFA PLANTS GROWN ON SANDY UPLAND. INOCULATED AND INTERNAL INFECTION PRODUCED WITHOUT NODULES. *B.*—SMALL ALFALFA PLANTS GROWN ON RICH BOTTOM LAND. INOCULATED FROM MELILOTUS FIELD.

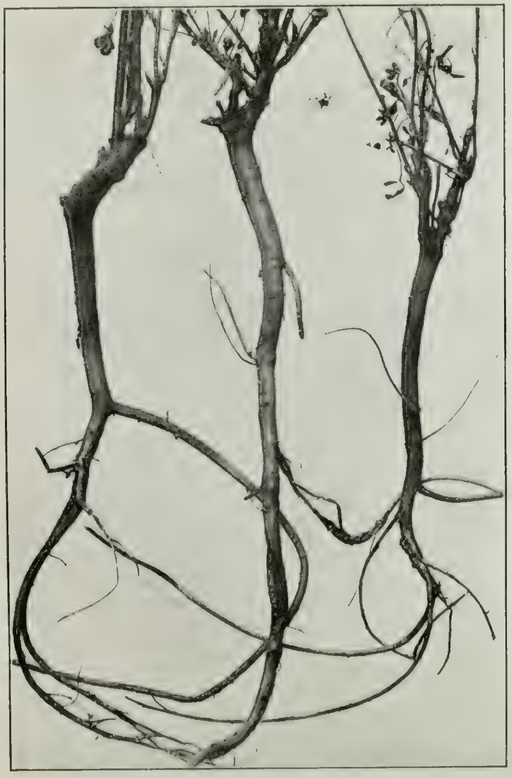


FIG. 1.—ALFALFA ONE YEAR OLD.

Few remaining plants from field which completely failed. Inoculated with culture improperly prepared.

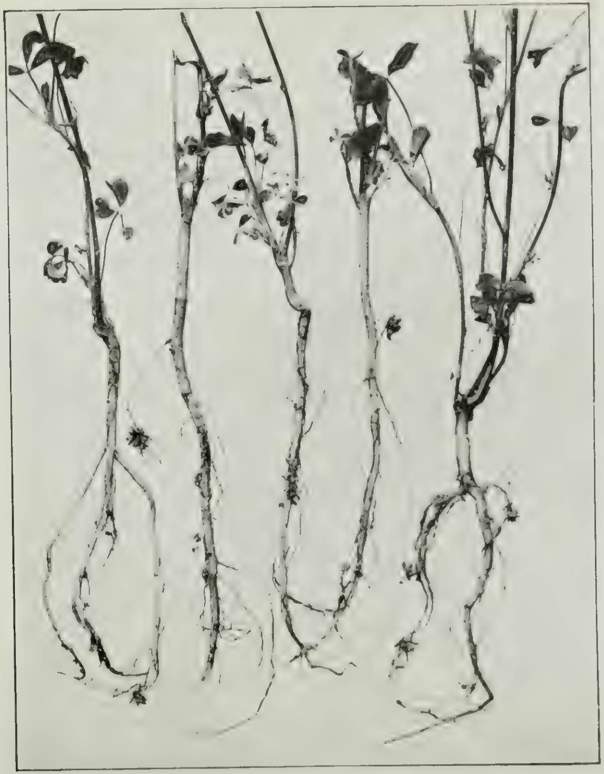
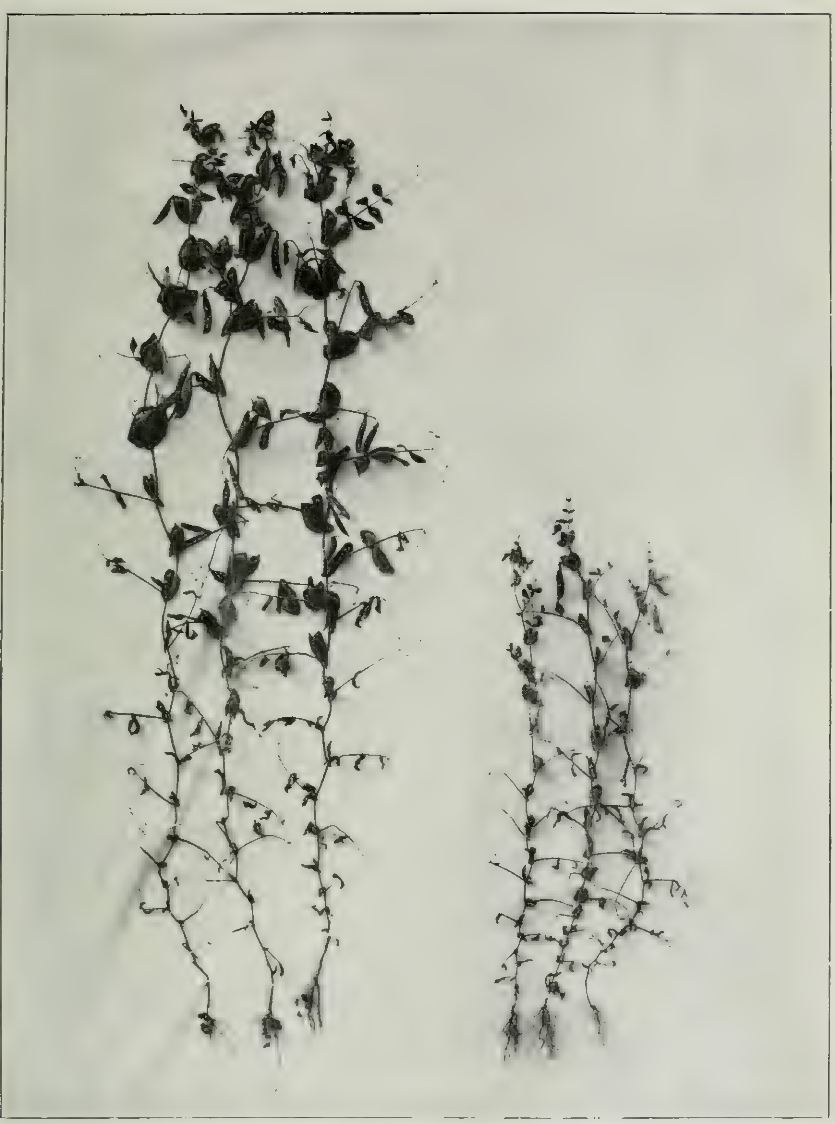


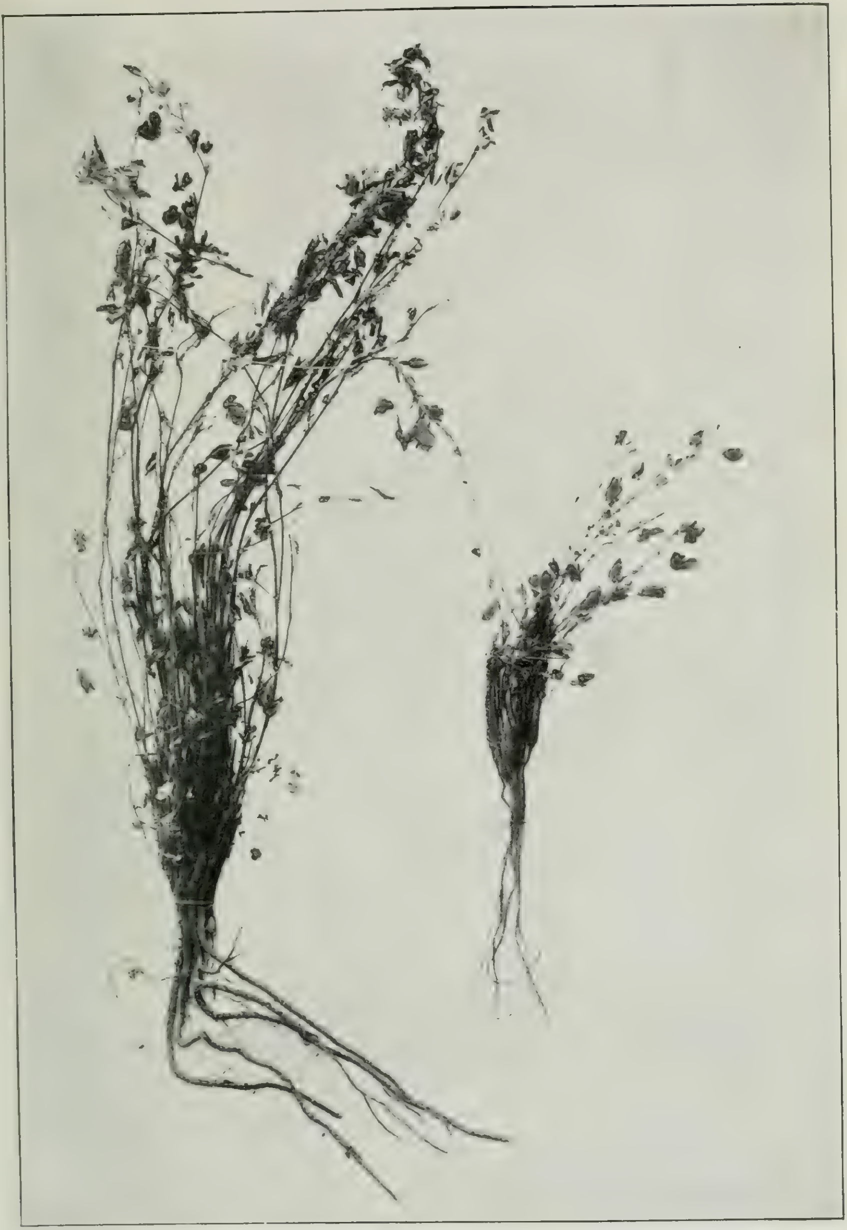
FIG. 2.—ALFALFA TWO MONTHS OLD.

Good stand. Field adjoining one which grew plants in figure 1 and soil exactly the same. Inoculated with bacteria from the same culture used in field which failed, but solution carefully prepared according to directions.

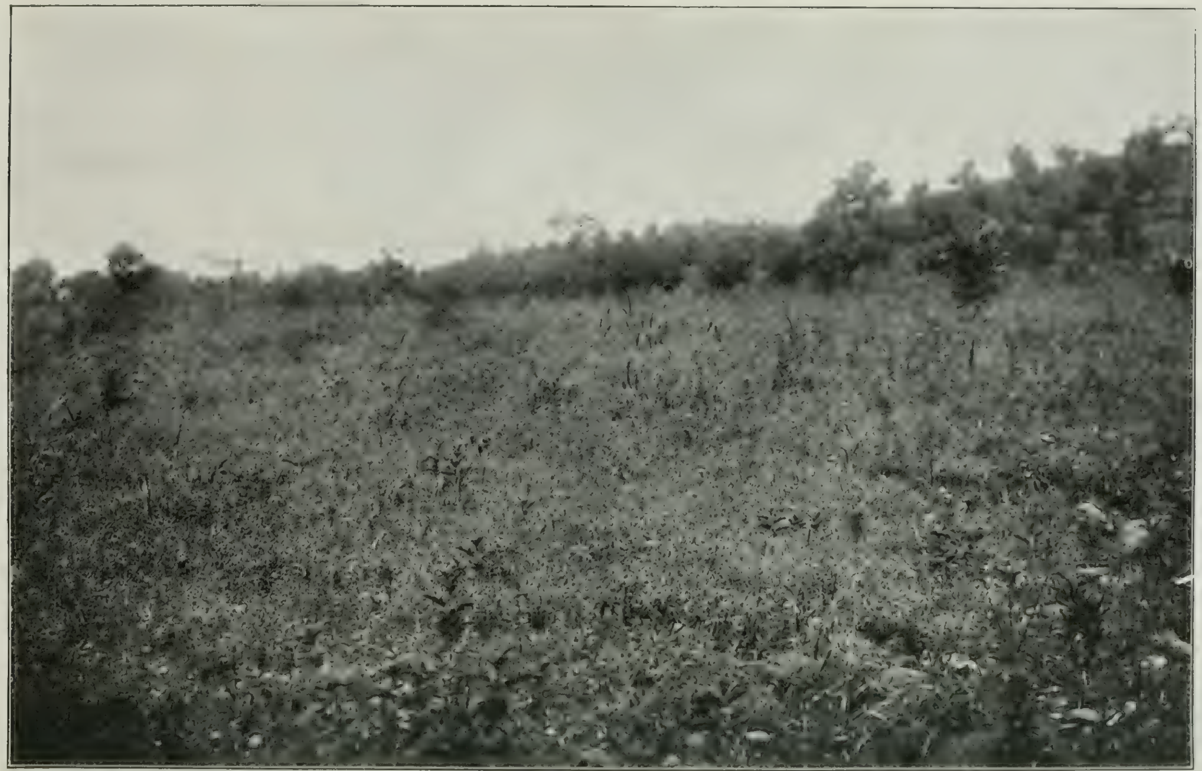


INOCULATED AND UNINOCULATED FIELD PEAS, GROWN BY J. T. CAMPBELL, HARTSTOWN, PA.

Photograph by Mr. Campbell.



ALFALFA PLANTS FROM DIFFERENT PARTS OF THE SAME FIELD, THE GREATER GROWTH BEING DUE TO SUCCESSFUL INOCULATION. FARM OF A. W. BRAYTON, MT. MORRIS, ILL.



GROUND THICKLY COVERED WITH ALFALFA TWO MONTHS AFTER SEEDING ON SOIL WHERE PREVIOUS ATTEMPTS TO GROW THIS CROP WITHOUT INOCULATION HAD ABSOLUTELY FAILED TO GET A CATCH. FARM OF W. W. GILES, OCCOQUAN, VA., JULY 28, 1904.

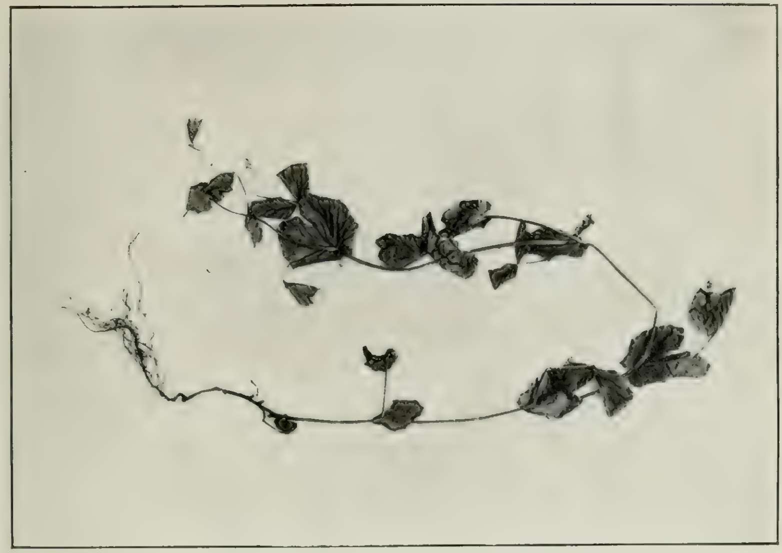


FIG. 1.—BEST VINE IN UNINOCULATED ROW OF PEAS GROWN BY JOHN R. SPEARS, NORTHWOOD, N. Y.

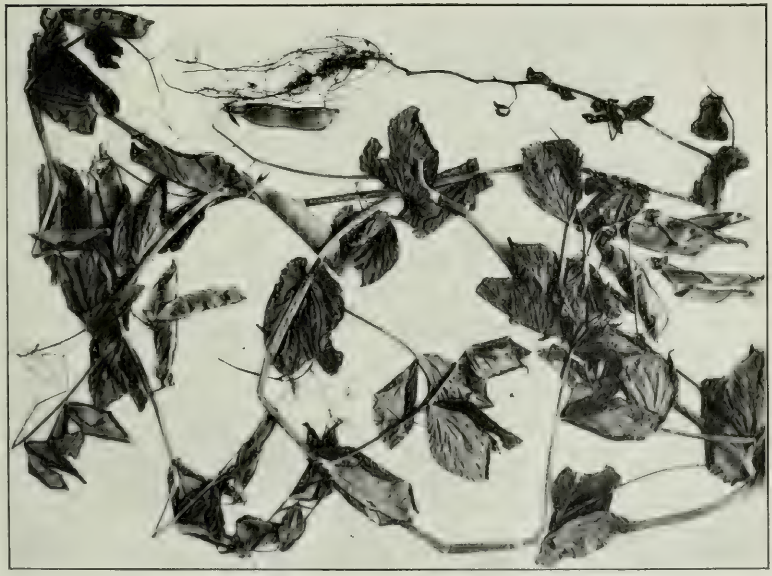


FIG. 2.—BEST VINE IN INOCULATED ROW OF PEAS GROWN BY JOHN R. SPEARS, NORTHWOOD, N. Y.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 72.

B. T. GALLOWAY, *Chief of Bureau.*

MISCELLANEOUS PAPERS.

I. CULTIVATION OF WHEAT IN PERMANENT ALFALFA FIELDS.

By DAVID FAIRCHILD, *Agricultural Explorer.*

II. THE SALT WATER LIMITS OF WILD RICE.

By CARL S. SCOFIELD, *Botanist, Grain Grade Investigations.*

III. EXTERMINATION OF JOHNSON GRASS.

By W. J. SPILLMAN, *Agrostologist.*

IV. INOCULATION OF SOIL WITH NITROGEN-FIXING BACTERIA.

By A. F. WOODS, *Acting Chief of Bureau.*

ISSUED JUNE 24, 1905.

239383
13 1.30

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

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3

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[a] The four papers constituting this Bulletin were issued in separate form on December 9, 1904, January 25, May 20, and May 25, 1905, respectively.

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MISCELLANEOUS PAPERS.

B. P. I.—130. S. P. I. D.—41.

I.—CULTIVATION OF WHEAT IN PERMANENT ALFALFA FIELDS.[a]

By **David Fairchild**, *Agricultural Explorer, Seed and Plant Introduction and Distribution.*

Wheat and alfalfa are being successfully grown together at the same time on the dry uplands of North Africa. Alfalfa, although doubtless one of the greatest forage crops in the world, has not so far in America been capable of utilization in a short rotation with wheat, but the recent experiments of a Swiss agriculturist in Algeria have proved that wheat and alfalfa can be grown to decided advantage in alternate rows.

During an exploring trip which the writer made for the Office of Seed and Plant Introduction and Distribution, in company with Mr. C. S. Scofield, a visit was made to Sétif, Algeria, where Mr. G. Ryf, in charge of the Swiss settlement there, has some remarkable experimental grounds. We noted, among the numerous interesting things with which Mr. Ryf was experimenting, a field of alfalfa planted in rows 3 feet apart, between which rows, he assured us, he grew every other year a crop of durum wheat. Since making this observation in Algeria in 1901, the attention of the writer has been called to the fact that such a rotation, if it can strictly be called a rotation, is not practiced in regions in America which are similar to the dry uplands of western Algeria so far as climate and soil are concerned, and it has seemed worth while to describe this simple method which Mr. Ryf has discovered and which he has now in satisfactory operation on his place.

---

[a] Alfalfa is probably the greatest fodder crop now grown in America, and wheat still holds its place as one of our most important cultures. The immense areas of wheat land in the Northwest, and the spread of durum wheat cultivation into the arid Southwest, where alfalfa is the principal fodder crop, should make unusually interesting the experiment of Mr. Ryf as reported in this paper by Mr. Fairchild.

With the present increasing interest in dry-land farming in portions of the West, notably in Utah and Montana, the present paper is very timely, and measures should by all means be taken to give the method a proper trial.

The observations of which this is a report were made by Mr. Fairchild and Mr. C. S. Scofield during their explorations in Algeria in 1901, but at that time the experiments of Mr. Ryf had not progressed far enough to merit calling them to the attention of American cultivators.

A. J. Pieters, *Botanist in Charge.*

Office of Seed and Plant Introduction and Distribution,
Washington, D. C., November 19, 1904.

In response to a letter of inquiry, the writer received a communication from Mr. Ryf, dated August 12, 1904, of which a free translation from the French follows:

> I believe more and more firmly that lucern[a] is destined to play an important rôle in all dry countries where forage is scarce. The value of the intercalary culture of cereals in lucern has been proved. I believe it to be rational and to solve the great problem of an economical manure crop. After numerous trials with planting lucern in rows at different distances apart, we have at last found that a distance of about 40 inches between double rows of the plant is most satisfactory. The distance between the single rows is uniformly about 4 inches. Formerly we sowed the lucern in single rows, but we have found it surer to sow it in double rows. With good seeders the work of sowing is not difficult. The space of 40 inches between the double rows of lucern we sow ordinarily with only three rows of wheat or other cereal, each row occupying about 7 inches and the double row of lucern 12 inches, making a total of 40 inches. The space between the two rows of lucern is cultivated two or three times. In one of these cultivations the earth is turned toward the rows of lucern; in the other, away from them. After each cultivation a harrow (and sometimes a roller) is run over the ground, providing there are stones or large clods. These spaces between the rows of lucern are sown only one year out of every two, the yield in forage during the year in which the ground is left fallow compensating largely for the loss which is incurred by not planting the ground. In very good soils our good indigenous varieties of lucern make such a growth that the rows join one another, notwithstanding the considerable distance of nearly 40 inches which separates them. A field during the fallow period looks as if it had been sown broadcast, or at least drilled in lines very close together. We get thus, on dry soil, without irrigation, two or three cuttings of lucern, and pasturage more or less abundant during the remainder of the year. We feared that lucern might injure the cereals planted between the rows, but there has been no reason for this fear. I would add that at the time of the plowing preparatory to sowing the ground we take pains to cut off with the colter and plowshare, both of which are kept well sharpened, masses of the lucern roots. This operation in a measure checks the growth of the latter during the vegetative period of the cereals, but being a plant of vigorous spreading habits it soon sends out new roots and shoots in such a way that the following year it has regained all of its former vigor.
>
> There are very considerable advantages in this method of culture. The

---

[a] The French name *luzerne* is applied in Algeria, as elsewhere, to *Medicago sativa* Linn., which in America is called alfalfa.

lucern sends its roots from 1 to 3 meters (3.28 to 9.84 feet) deep into the subsoil and draws from it the water necessary for its growth. It absorbs, as well, nitrogen from the atmosphere, which is the other source of food. From the roots, which are amputated periodically, is secured a green fertilizer which, according to numerous experiments, is equivalent to a good dressing of barnyard manure. But this manure, in the form of amputated roots, plays still another rôle quite as important in dry land. It serves the purpose of a water reservoir. In fact, these roots in decomposing become like little sponges which run through the soil, and in these the rain water accumulates. These roots, penetrating deeply, thus constitute reservoirs of humidity, at the same time breaking up and rotting in the soil and subsoil, in this way furnishing nourishment and moisture to the cereals which are grown between the rows, and playing the rôle of excavator at the same time.

Our indigenous varieties of lucern, which have been acclimated in this region since Roman times, are incomparably more valuable than the cultivated lucern called *de Provence* or *de Poitou*. The former varieties are as strong and hardy as the latter are exacting and delicate, and they will last for several centuries, if not always, defending themselves victoriously against the weeds, which they often kill in place of being killed by them. Among these indigenous species there is one which is in all respects superior, and we are doing our best to propagate this.

A number of cultivators have adopted the intercalary culture of lucern and cereals. One proprietor in Tunis wrote me recently that he was going to try 50 hectares (123.55 acres) of this intercalary culture. As for myself, I extend my cultures each year, and expect to sow next spring as large an area as the seed selected will permit. A severe storm on July 13 destroyed a large part of my lucern which had been cut for seed, which fact I regret exceedingly. I believe that our indigenous lucerns would grow in Montana and other of your cold and dry regions, but under these conditions there are certain precautions to be taken in order to bring the young plants to maturity. Once well established, no freezes would destroy them; of this I am convinced. Our climate on the high plateau of Algeria, although not so cold in winter, resembles singularly that of the dry States in the central and western portions of your country.

Whether or not a place for this unusual method of cultivation can be found in the drier regions of this country is well worth finding out, in view of the fact that so successful an experimenter and so practical a farmer as Mr. Ryf has pronounced it a commercial success in Algeria after several years of trial.

II.—THE SALT WATER LIMITS OF WILD RICE.[a]

By **Carl S. Scofield**, *Botanist in Charge of Grain Grade Investigations; Botanical Investigations and Experiments.*

INTRODUCTION.

Wild rice (*Zizania aquatica* L.) is naturally a fresh-water plant, and its growth along the Atlantic coast of the United States is confined for the most part to sluggish streams or to those deep estuaries that are diluted by a large amount of fresh water. There are in many of these streams and estuaries large areas of marsh lands or mud flats that are submerged and exposed alternately by the tide. Wherever the water is sufficiently fresh, such conditions are almost ideal for its growth, and in many places large wild rice fields now exist, but there are still other places of similar nature where the plant is not found and where attempts to establish it have been made without success. These failures have been ascribed usually to the poor quality of the seed used in planting, and probably this has been one of the important causes.

An investigation undertaken two years ago[b] in cooperation with the Seed Laboratory of this Department, demonstrated the fact that wild rice seed should never become dry if its vitality is to be preserved. It was also shown that this seed can be gathered and stored over winter, if need be, provided it is kept in water that is very cold, and well aerated or frequently changed, or even frozen.

---

[a] Wild rice is one of the favorite foods of wild ducks and other game birds in the eastern United States, and owners of shooting preserves often desire to plant it in order to increase the richness of their feeding grounds and thereby attract larger numbers of birds. Plantings heretofore made have often proved failures, particularly in brackish waters along the seacoast. The causes of failure under these circumstances have been two—the use of seed which had been so dried in the curing process as to destroy its vitality, and an excess of salt in the water, by reason of which either the seeds or the young plants were killed. A method of harvesting and curing which would insure vitality in wild rice seed has already been described in Bulletin No. 50 of the Bureau of Plant Industry. In the present paper are recorded the results of an inquiry into the degree of salinity which the plants will withstand. This information will make it possible to ascertain in advance, by a determination of the salinity of a particular body of water, whether wild rice planting can or can not succeed.

Frederick V. Coville, *Botanist.*

Office of Botanical Investigations and Experiments,

Washington, D. C., November 30, 1904.

[b] See Bulletin No. 50 of the Bureau of Plant Industry, "Wild Rice: Its Uses and Propagation."

From numerous letters received during the year from various points along the coast, it has become evident that not all previous failures were due to the lack of vitality of the seed. It has been a well-recognized fact that wild rice will not grow in salt water; that is, in water as salt as that of the ocean, but just what its salt water limits are seems never to have been determined, or at least no definite information on this point is available. It was obvious from the nature of the inquiries received that some such information was needed, and consequently some investigations have been made near Washington, where wild rice grows along streams flowing into Chesapeake Bay. Three separate regions were examined, and two of these gave excellent opportunities for determining the salt water limits of the plant.

As wild rice is a thoroughly aquatic plant—that is, grows on soil entirely submerged for at least a part of the day during its period of growth—the tests for salinity were confined to the water surrounding the plants. The difficulties attendant upon determining the quantity of water involved in cases of soil samples threatened to complicate the investigation without adding materially to the results desired.

THE METHOD OF TESTING SALINITY.

The salt content of the water was determined by means of an electrolytic bridge designed by Dr. Lyman J. Briggs, of the Bureau of Soils of this Department, and such as is now in general use by that Bureau. The principle involved in the use of this instrument is that with a given temperature the electrical conductivity of the water increases with the amount of salt in solution, or, conversely, the electrical resistance of the water decreases as its salinity increases. The instrument is compact, portable, and simple of operation and gives results that are accurate to a high degree and capable of almost direct reading. All the difficulties involved in securing a large number of samples and making numerous laboratory analyses are, therefore, obviated and a survey of any locality may be made and the salt content of the water determined on the spot, where such information is of the greatest value in interpreting the distribution of the plants studied.

The regions surveyed were visited by boat and the water was examined both where the wild rice grew vigorously and where its growth was obviously inhibited by the excessive salt content of the water. A special form of cell, designed by Doctor Briggs for use in testing irrigation water, was found best adapted to this work. This cell consists of two platinum terminals, coated with platinum black, and protected by a perforated hard-rubber bulb. The cell is attached to the bridge by insulated leads and immersed in the water to be tested. The bridge readings are given in ohms, and a calibration by measuring the resistance of solutions of known concentration suffices to transfer these readings into the scale of percentages by weight or parts of a normal solution, as desired.

In the following notes the instrument readings are used largely, while in the accompanying table the relations of those readings to both the percentage scale and parts of a normal solution are given.

THE REGIONS INVESTIGATED.

The first region investigated was that of the Potomac River between the city of Washington and Chesapeake Bay. Wild rice was reported as abundant in the deep inlets, or so-called rivers, penetrating both shores of the Potomac near its mouth. It was found, however, that these inlets receive so little fresh water in proportion to their size that the water in them is approximately as salty as that of Chesapeake Bay, and they contained no wild rice. There were, however, many clusters and even small fields of salt reed grass (*Spartina polystachya* (Michx.) Ell.) and also of the narrow panicum (*Panicum digitarioides* Carpenter) that may possibly have been mistaken for Zizania by casual observation from a distance.

There was some wild rice growing along the shores of the Potomac River below Washington as far down as Widewater, Va., near which point the water becomes salty; but the growth was so scattering and so obviously influenced by factors other than the salinity of the water that no opportunity was found to test the limiting conditions with respect to this factor.

The second region investigated was at the head of a deep inlet from Chesapeake Bay, northeast of Baltimore, Md. This inlet is known as the Gunpowder River. It receives fresh water from two small streams known as the Gunpowder Falls and the Little Gunpowder. These streams annually carry out and deposit in the head of the inlet large quantities of mud, through which several narrow channels are kept open by the current. The mud flats thus formed are submerged to the depth of a foot or more at flood tide and exposed by several inches at low tide.

This annual mud deposit is gradually filling up the inlet, and over the land thus made the progress of vegetation is to be seen in well-marked stages. The first plant to appear is pickerel weed (*Pontederia cordata* L.). These usually grow on the freshly deposited mud and doubtless aid greatly in holding it in place. These plants are followed by wild rice in isolated clusters which give seed enough to produce a dense and luxuriant growth the year following. Meanwhile additional deposits of silt, together with the débris from the large stems of the wild rice plants, have transformed these soft mud flats into firm land, and the wild rice is gradually replaced by cattails (*Typha latifolia* L.) and various species of sedges and grasses.

The combined volume of the two streams above mentioned is sufficient to dilute the otherwise salty water of the Gunpowder River for a considerable distance out over the mud flats, and, so far as could be ascertained by careful observation, all other conditions are sufficiently uniform so that the spread of the wild rice into the river is limited only by the salinity of the water. In other words, conditions at the head of the Gunpowder River appear to be such that the salt water limits of the particular variety of wild rice growing there can be definitely measured.

There is, of course, the universal complication of tide movement, with the result that the concentration varies at any point in the critical zone as the tide alternately rises and falls. While the measurements of salinity were not continued at a given point in this zone throughout a complete cycle of tide movement, they were made for a sufficiently long period to give an approximate idea of the range of concentration.

The conformation of the mud flats and channels at this point is such that there is very little actual inflow of tide water over the rice fields. The incoming tide is little more than sufficient to stop the outflowing fresh water, even in the open channels, so that the concentration at any point within the wild rice field is practically the same at flood tide as when the tide has more than half run out.

At the mouths of the two streams mentioned, the Gunpowder Falls and the Little Gunpowder, the water at the beginning of ebb tide gave about 1,400 ohms resistance. (See table, p. 14.) Out beyond this point were the large fields of wild rice cut by open channels. Among the most luxuriant growth of wild rice, where the water was practically stagnant, the resistance was about 300 ohms, varying from 275 to 325 ohms at different points.

On the outer edge of the wild rice field and in the channels near this edge at flood tide the resistance was 150 ohms or less, while the open water outside of the field gave a resistance as low as 125 ohms. This latter reading corresponds to a 0.03 normal solution of sodium chlorid, and at this point evidently marked the limits of the resistance of wild rice to salt water.

The third region investigated was the Patuxent River in Maryland, from Chesapeake Bay to the head of navigation, which is Leon's Landing, a point just north of where the Chesapeake Beach Railroad crosses this river.

The Patuxent River, for a considerable distance above its mouth, is very wide in proportion to the volume of water it contributes to Chesapeake Bay, so that it does not form the conventional delta. As a result the tide is very pronounced as the stream narrows to the proportions necessary to deliver its water, and the line between fresh and salt water shifts for a long distance with each tide.

This action of the large tide movement considerably complicated the task of measuring the concentration of the water with which the plants along the stream are actually surrounded. It was found, however, that the wild rice plants, especially those along the lower part of the river, where the salt content was fairly high, are so situated that they have a minimum of actual water movement past them. In other words, where the conditions are such that the salt content of the river water at high tide is considerably greater than that to which the wild rice is accustomed, the plants along this portion of the stream were surrounded by water considerably fresher than that of the stream itself. The maximum concentration in which wild rice plants were found extensively growing in the lower river was about 0.03 of a normal solution of sodium chlorid, equivalent to a resistance of 125 ohms. Occasional plants were found, however, where the resistance was as low as 60 ohms, but these were so situated that they were doubtless surrounded a large part of the time by water much fresher than this. This latter test was made shortly after high tide and the plants were found in a little cove of slack water. It is probable this represents nearly the maximum concentration to which the plants were exposed.

A careful survey of the river below this point, White's Landing, failed to show any quantity of wild rice. There were occasional plants farther down the river, but always in situations well inland, that were probably fed by springs, so that the water of the overflow was considerably diluted. From White's Landing on up the river the concentration of the water diminished rapidly and the mud flats on either shore produced an abundance of wild rice. In fact, from Nottingham north to the head of navigation, wild rice is the most conspicuous feature of the vegetation bordering the river.

CONCLUSIONS.

From the surveys thus made in the vicinity of Washington, it seems fair to assume that the salt water limit of wild rice is approximately represented by 0.03 of the normal solution of sodium chlorid. This is very considerably less than the concentration of the water of Chesapeake Bay, which has a resistance of about 20 ohms, or a concentration equivalent to about 0.28 of a normal solution of sodium chlorid. It is also obvious that this represents about the maximum salt water resistance of the species in the regions examined, since the growth along the limiting zone is abundant, and in the nature of the case the whole tendency is toward the selection of plants able to resist higher concentrations. The streams along which these plants grow on the Atlantic coast usually flow into salt water. Nearly all of them carry down large deposits of mud and form shallow deltas which give physical conditions best adapted to the plant, and any individuals able to succeed in saltier water would considerably aid the species in its conquest of territory.

When, therefore, the question of establishing cultures of wild rice along the coast streams is being considered, it is highly important that the concentration of the water covering these areas be determined, for this appears to be the factor of the greatest importance in ascertaining the possibility of establishing such cultures.

It may also be added that the salt water limits of wild rice may be determined approximately by the simple test of taste. When water is appreciably salty to the taste, it is too salty for the successful growth of this plant.

Table showing the relation between the readings of the testing cell used in the above surveys and the parts of a normal, and the percentage by weight solutions of sodium chlorid; also the relation of these concentrations to the growth of wild rice.

Resistance of water in cell at 80° F.	Parts of a normal solution of NaCl.	Percentage solution of NaCl.	Notes
Ohms.			
20	0.2800	1.6380	Concentration of Chesapeake Bay; no wild rice.[a]
60	0.0640	0.3740	Limit of occasional plants; excessive for successful growth.
125	0.0300	0.1755	Limit of wild rice growth; slight taste of salt in water.
250	0.0140	0.0820	Luxuriant growth of wild rice; no taste of salt in water.
1,400	0.0027	0.0158	Water at the mouth of Gunpowder Falls: abundant wild rice.
3,700	0.0010	0.0058	Water of the upper Patuxent and Potomac rivers; abundant wild rice.

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[a] According to this test the water of Chesapeake Bay is considerably fresher than that of the Atlantic Ocean. Makin (Chemical News, 77: 155 and 171) finds that ocean water contains 3.631 per cent of solids, with the more abundant salts in the following proportions: NaCl, 76.915 per cent; $MgCl_2$, 11.407 per cent; $MgSO_4$, 4.483 per cent; $CaSO_4$, 4.226 per cent; K_2SO_4, 2.468 per cent.

III.—EXTERMINATION OF JOHNSON GRASS.[a]

By W. J. Spillman, *Agrostologist in Charge of Grass and Forage Plant Investigations.*

INTRODUCTION.

On account of the importance of the subject to the farmers of the South, the following notes, giving results of certain tests of methods of exterminating Johnson grass, are published in advance of the completion of the experiments undertaken. The complete investigations include not only a test of various cultural methods for the extermination of this pest, but also the use of various chemical preparations for this purpose, including such materials as crude petroleum (which is obtainable at very low prices in parts of the Johnson grass country) and various mixtures containing arsenic. The complete success of some of the cultural methods used in the experiments renders it important that they should be made available to the public at once. These methods are practicable on cultivated land, but do not apply to fence rows, ditch banks, or railway rights of way. It is hoped that effective methods of controlling or even of eradicating Johnson grass in the latter situations may also be developed.

The cultural tests here reported were conducted by the writer on the farm of Mr. J. B. Gay, of Columbus, Tex., and acknowledgment is made of the very faithful manner in which Mr. Gay has carried out instructions in connection with the conduct of the experiments. Three somewhat different methods of handling the soil were tested. The preliminary treatment of the soil was the same in each case.

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[a] Johnson grass is probably the most troublesome weed in the Southern States. In the autumn of 1902 investigations were begun with a view to devising practical means of eradicating it. These investigations are still in progress, but the very definite results thus far secured on one phase of the problem, together with the urgent need of information on the subject, seem to justify the publication of the data already at hand. The method, the results of which are contained in this paper, is applicable only to open fields. Methods of dealing with this pest in roadways, on ditch banks, and along the rights of way of railroads will be discussed in a later publication.

W. J. Spillman, *Agrostologist.*

Office of Grass and Forage Plant Investigations,
Washington, D. C., March 17, 1905.

variation in the methods occurring in connection with the different cropping systems followed on the different plats.

CHARACTER OF THE SOIL.

The land on which these experiments were conducted consisted partly of heavy, dark-colored alluvial soil, inclined to be wet. The south end of the plats extended to a lighter type of soil of medium character. The results were practically the same on the two types of soil. This land had been abandoned to Johnson grass for some years and was in the middle of a large field which was badly infested and in which cotton had been grown for some years. At the time these experiments were undertaken it was believed by many that the eradication of Johnson grass was impracticable on account of the cost; but since that time the writer has learned of many farmers who have completely rid their farms of this pest by methods quite similar to those used in these experiments. Methods radically different from these have also been reported to be completely successful, though the writer has no personal knowledge to substantiate the claims made for the various methods.

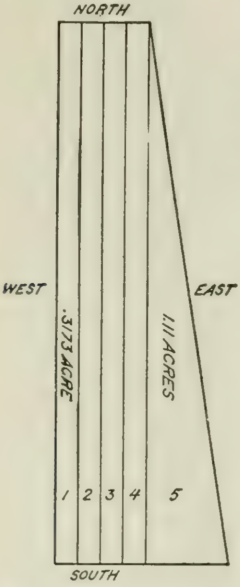


FIG. 1.—Diagram of experimental plats on the farm of Mr. J. B. Gay, Columbus, Tex.

METHODS OF TREATMENT.

The various methods of treatment will be considered in the order of their effectiveness. Figure 1 shows a diagram of the plats upon which the experiments were conducted. The general plan of the experiments was as follows: Plats 1 and 2 were devoted to rye and barley, respectively, during the winter, cowpeas the first summer, cereals again the next winter, and cotton the second summer. Plat 3 was devoted to cotton both years. Plat 4 was left bare the first year and devoted to cotton the second year. The triangular plat on the east side of the field, plat 5 in the diagram, was left in Johnson grass for the sake of comparison.

The preliminary treatment of plats 1, 2, 3, and 4 was identical and was as follows: In August, 1902, these plats were plowed with a disk plow to a depth of 4 or 5 inches. At this time the ground was dry and hard and a considerable growth of Johnson grass on the plats was turned under. On September 2, no rain having intervened, an attempt was made to remove the Johnson grass rootstocks from the ground by means of the implement shown in figure 2, here called a root digger, but called by the manufacturers a grass hoe. On account of the cloddy condition of the soil the root digger failed to do satisfactory work. On the 15th and 16th of October, after the land had received sufficient rain to put it in good condition, it was replowed with a two-horse turning plow to a depth of about 4 inches, the utmost care being used to cut and turn every inch of soil in order that no Johnson grass roots might remain uncut. This plowing left the land in excellent condition. On the next day the root digger was used on this land, first crosswise of the furrows and then lengthwise. It is estimated that this operation removed fully 90 per cent of the Johnson grass roots from the soil and left them on the surface. They were then raked off with an ordinary horserake and removed from the land. On October 20, plat 1 was sown to rye and plat 2 to barley, plats 3 and 4 being left bare during the winter. The winter season proved to be very wet and neither the rye nor the barley made sufficient growth to justify cutting for hay in the spring. On April 7, 1903, all four of these plats were plowed again with a two-horse turning plow, the rye and barley on plats 1 and 2 being turned under.

The treatment given each of the plats will now be taken up separately. As the treatment given plat 4 resulted in the complete eradication of the grass, that will be described first.

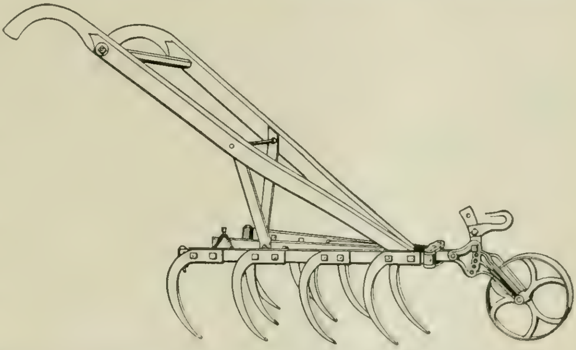


Fig. 2.—Root digger (so-called grass hoe) used in the experiments.

As previously stated, plat 4 had been plowed twice the previous autumn and treated twice with the root digger. It was again plowed on April 7. On May 4 a drag harrow was run over it. On May 18 it was run over with an ordinary heel-scrape, or heel-sweep, as it is called in many parts of the South. The implement used is shown in figure 3, an implement which shaves off an inch or two of the surface of the soil. The ground was harrowed again with an ordinary drag harrow the same day. The heel-scrape was run over the land again on July 17 and again on August 31. After that date no Johnson grass appeared on this plat. The subsequent treatment of the plat consisted of harrowing, on October 26, merely to smooth the surface.

In November, 1903, when the writer visited these plats, there was not a sprig of Johnson grass on plat 4, and Mr. Gay stated that none had appeared since the last of August. Plate I, figure 1, shows the appearance of this plat on November 24, 1903, just after it had been laid off for cabbages. To the right of the plat will be seen the original Johnson grass sod, while to the left is the cotton grown on plat 3 during the summer of 1903. The grass roots shown are those of Colorado grass and not of Johnson grass.

On account of the unfavorable season, cabbages were not planted on plat 4, as contemplated in 1903, and the plat remained bare during the winter. During the summer of 1904 this plat was devoted to cotton. It was plowed on March 29 with an ordinary turning plow and cotton was planted the same day. This cotton was cultivated with the heel-sweep on April 20, at which time about half a dozen sprigs of Johnson grass were found along the eastern margin next the Johnson grass sod. On May 24 the heel-scrape was again used, on June 16 the cotton was chopped, on June 28 it was plowed again with the scrape, the final cultivation with the scrape being made on July 15. The cotton on this plat grew very rank, so much so, in fact, that it shed a great many of its bolls. In addition, the boll weevil destroyed a very large portion of the crop, so that the yield of cotton was only one-fourth of a bale per acre. Plate I, figure 2, shows the condition of this plat on August 29, 1904, just two years from the time the experiments began. It is seen that the growth of the cotton was very rank, no Johnson grass being present. As heretofore stated, there were a few sprigs of Johnson grass on this plat, but they were along the east side, adjacent to the Johnson grass sod, and were probably due to invading roots from the old sod. It will be seen that the summer-fallowing given this plat during the summer of 1903, added to the work of the root digger in the autumn of 1902, completely exterminated the grass by the last of August. The number of cultivations given this plat during 1903 included one plowing with the turning plow in the spring and the use of the heel-scrape once in the middle of May, again the middle of July, and again the last of August. It would, of course, be impracticable for a farmer to treat his whole farm by this method during a single season. The method, however, is entirely practicable if a small portion of the farm is treated each year and great care used not to allow Johnson grass to start again from seed on the portion of the farm that has already been cleared.

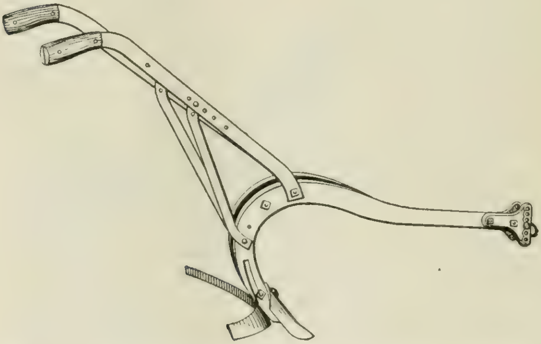


FIG. 3.—Stock, with shovel point and heel-sweep attached.

The next most successful treatment was that given plat 3. The roots were dug on this plat in the autumn of 1902, just as on plat 4, and plat 3 remained bare during the winter. In the summer of 1903 this plat was devoted to cotton. The land was plowed with a two-horse turning plow on April 7. On May 4 a drag harrow was run over it, and on May 18 it was planted to cotton. The cotton was chopped first on June 25, and was cultivated with the heel-scrape on June 26 and again on July 15. It was chopped again on July 23 and August 17. The last cultivation with the scrape was given on August 31. Although the weevil was very bad, the yield of cotton was one-third of a bale per acre. Plate II, figure 1, shows the condition of this plat on November 24. The same plat was devoted to cotton again during the summer of 1904, and no more Johnson grass was visible than may be seen in Plate I, figure 1, from a photograph taken the year before. On this plat, in addition to the cultivation above mentioned, bunches of Johnson grass, as they appeared, were removed by hand before the growth had reached a height of 6 inches. This was very easy, since all of the sprouts that came were either from seed or from short pieces of roots left in the soil by the root digger.

From the experience with this plat it seems that it would be entirely feasible to eradicate Johnson grass completely in a single year in the following manner: First, in the autumn, at a time when the land is in good condition to cultivate, plow to a moderate depth with a turning plow, being careful to cut and turn every inch of soil. A good disk plow so set as to cut every inch of the soil would answer as well. Harrow the land immediately so as to get it smooth and well pulverized. It is perfectly useless to try to use the root digger unless the land is brought into excellent condition and is free from clods. The next treatment is to run over the land with some implement which acts on the same principle as the root digger shown in figure 2. First, run crosswise of the furrows and then lengthwise. The roots left on the surface by this treatment may either be removed from the field or left to decay during the winter. In the spring, plow the land again with the turning plow and then put it in cotton in the usual way and give the cotton ordinary good tillage. Pay no attention to the Johnson grass until the first sprigs get to be about 6 inches high, then go carefully over the land and pull out every bunch of Johnson grass visible. By doing this work carefully it will be possible to remove every sprig, root and branch, because the grass sprouts come from small loose pieces of roots in the soil. By repeating this operation, never allowing a sprig to get more than 6 inches high, the grass can be completely eradicated during the summer, and the amount of labor required will not be excessive. We have found that the treatment given in the autumn by the root digger leaves comparatively little to be done the next summer. This is probably the most practical method for eradicating the grass on cotton farms. Similar methods could be pursued in a cornfield, but the average farmer in the South will not give a cornfield the attention given a cotton field. It is therefore recommended that where this method is used for exterminating Johnson grass, cotton be grown the summer after the root digger is used in the autumn.

Very good results could doubtless be obtained by using the root digger on well-prepared land in the spring instead of in the autumn, but if the work is done in the autumn the cold weather of winter will kill a large number of roots that would otherwise remain to be destroyed by hand work the next summer.

The treatment given plats 1 and 2 was not as successful as that given plats 3 and 4, yet very good results were obtained. As already stated, these two plats were treated with the root digger in the autumn of 1902, and were then sown to winter grain. The next summer they were cultivated in cowpeas, no particular attention being given to the grass. The next winter they were again devoted to winter grain, while the next summer—that is, the summer of 1904—they were planted in cotton. Plate II, figure 2, shows the condition of these two plats on August 29, 1904, two years after the treatment began. When it is considered that this land was pure Johnson grass sod at the beginning, it will be seen that after two years, with no special treatment except the use of the root digger the first autumn, the land was comparatively free from grass; in fact, there was not enough grass to interfere in the slightest with the production of the cotton crop. Plate III shows the condition of the cotton crop of one of Mr. Gay's tenants a few yards from these plats. A careful study of the picture will show a few stalks of cotton among the Johnson grass. This picture could be duplicated on many other farms on the Colorado River, in the vicinity of Columbus, Tex. The principal difference in the treatment given the crop shown in Plate III and that shown in Plate II, figure 1, was in the use of the root digger the autumn previous.

IMPLEMENTS USED.

While the implement shown in figure 2 removes Johnson grass roots from well-prepared soil very effectively, the implement itself is an impracticable one. In the first place it is too small, and it therefore requires too much labor to treat the land. In the second place, the teeth soon clog with the roots and it is necessary to stop and raise the implement high enough to allow the roots to drop off and then start the team and hold the implement in the air until it has passed over the pile of roots. For the past year most of our energies have been directed to securing a more satisfactory implement for removing the roots from the soil. We have found that the teeth of the implement must be close enough together not to leave a space over 3 inches wide between the tracks of the teeth. At the same time, when these teeth are all placed in one row, they bank up the soil in front of them and do not allow the implement to pass through properly. On loose, sandy soil the teeth in the same row must be at least 6 inches apart; on ordinary loam soil, 9 inches; and it is probable that on heavy clay soil they would have to be a foot apart. From plans furnished by Mr. Gay the implement shown in figure 4 was constructed. This implement has two rows of teeth so set that when viewed from the rear the teeth are only 4½ inches apart, but it did not remove the roots from the soil nearly so completely as did the grass hoe (fig. 2). We are now constructing a new form of the implement shown in figure 4, having three rows of teeth, those in the same row being 9 inches apart, and the rows so set that the teeth make tracks only 3 inches apart. As soon as a practicable implement has been evolved the details of its construction will be made public. The roots collected by the teeth of the root digger are easily dumped by tilting the implement on end, first one way and then the other. The tilting may be done by means of the handles without stopping the team.

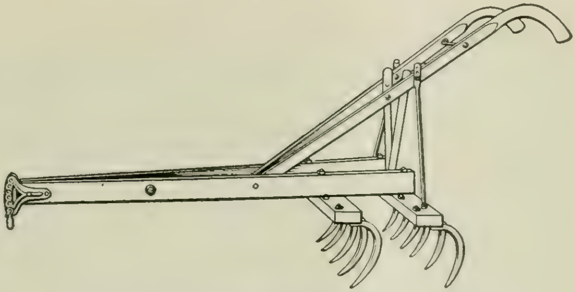


FIG. 4.—Root digger devised by Mr. J. B. Gay.

In the course of these investigations several different types of machines have been constructed and tried. One of these was constructed on the principle of the ordinary sulky hayrake, but having rigid steel teeth so set as to draw into the loose soil about 4 inches deep. The amount of labor involved in working this machine seems to render it impracticable; besides, it would be quite expensive. We are endeavoring to evolve an implement that can be constructed by any local smith. It is probable that a heavy drag harrow could be made to take the place of a root digger such as that used in these experiments. While it would not remove the roots from the soil so completely as the root digger and would therefore leave more hand work to be done the next summer, nevertheless it is believed it would be practicable to eradicate Johnson grass in this manner.

It is of course well known that Johnson grass can be eradicated by repeatedly plowing the land with a disk plow or a turning plow, but repeated plowing without the production of a crop is an expensive method of destroying the pest. By plowing in winter, thus leaving a large proportion of the roots exposed to cold weather, the stand of the grass can be reduced very materially.

THE PRODUCTION OF HAY.

It is the writer's belief that, with the adoption of thoroughly modern methods of tillage throughout the Johnson grass region, it may become practicable to utilize this grass for the production of hay without serious interference with the cultivation of other crops. Fall plowing, treatment with a root digger, or perhaps with a heavy spike-tooth harrow, combined with more or less hand pulling the next season, will so reduce the stand of grass that it will be several years before it will again seriously interfere with the production of cultivated crops. The land can then be allowed to go back to Johnson grass for two or three years for the purpose of hay production, thus adapting it to a rotation of five or six years. The writer, however, would not advise any farmer to sow Johnson grass on land that is free from it until more is known about methods of controlling it. It is very unfortunate that a grass which will produce three good crops of hay in an ordinary season should be so hard to control as to render it a very serious pest.

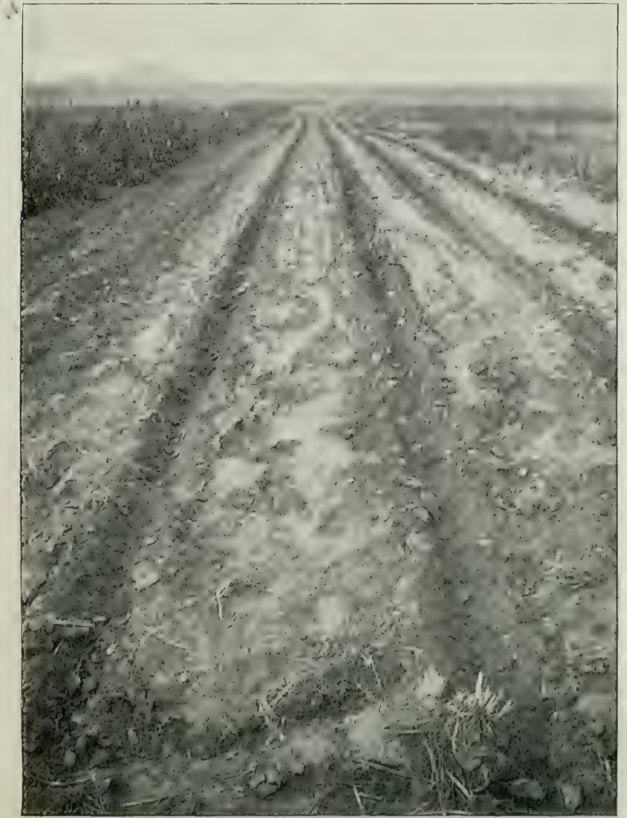


FIG. 1.—PLAT 4 ON NOVEMBER 24, 1903; JOHNSON GRASS SOD TO THE RIGHT.

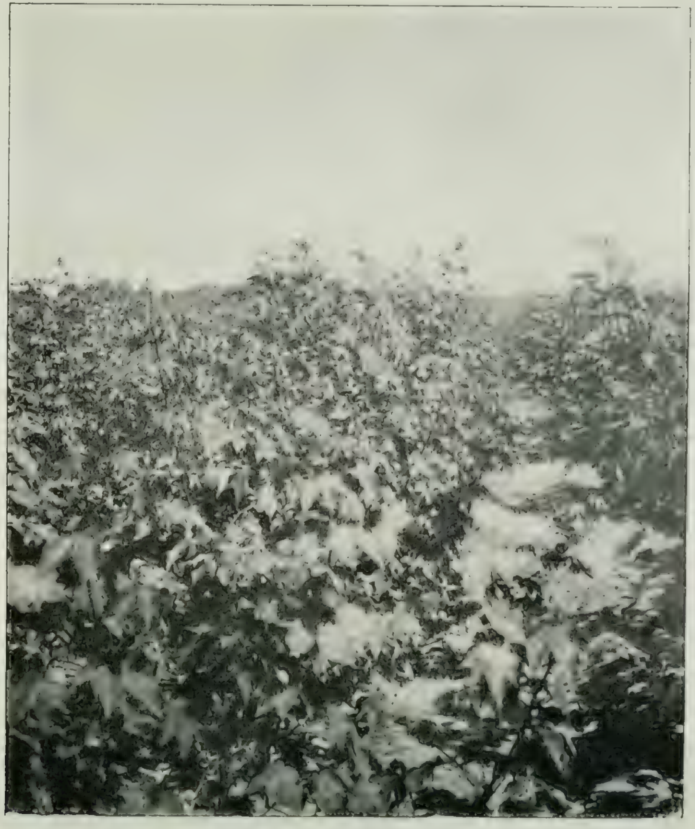


FIG. 2.—PLAT 4 ON AUGUST 29, 1904, TWO YEARS AFTER TREATMENT.

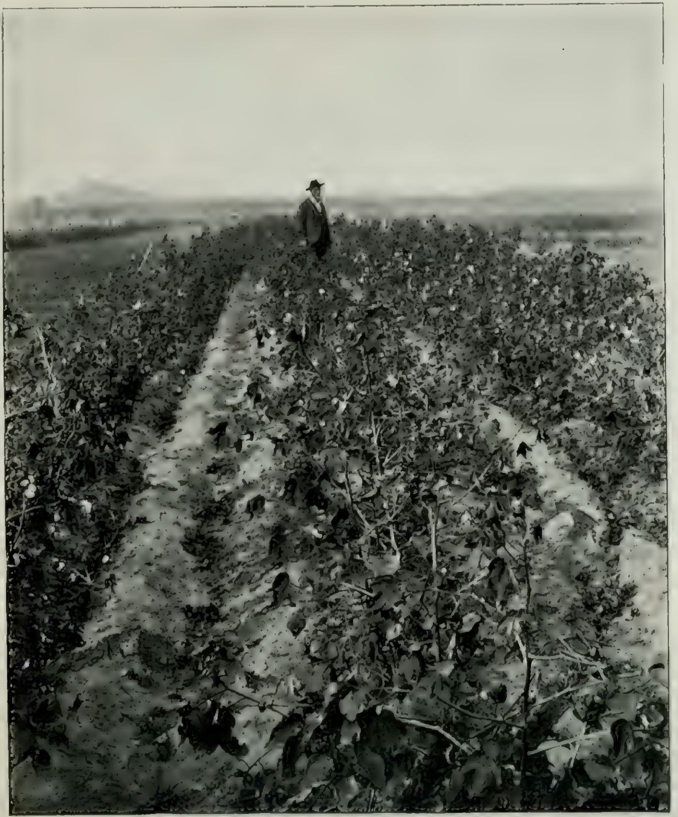


Fig. 1.—Plat 3 on November 24, 1903.

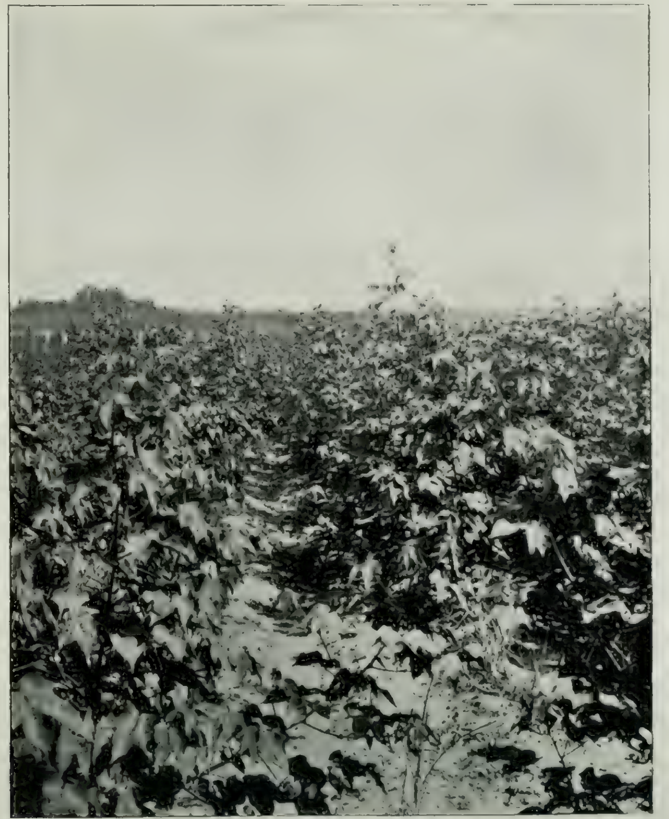
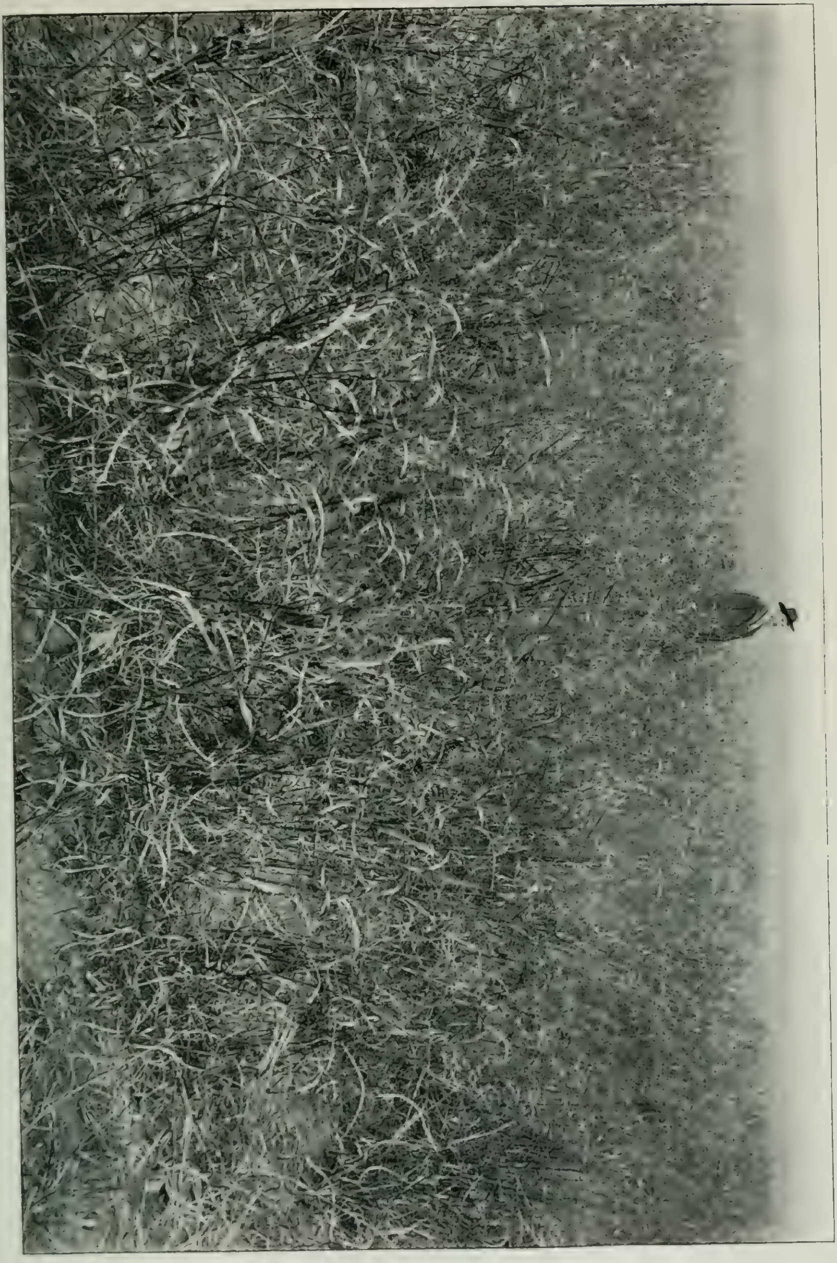


Fig. 2.—Plat 1 on August 29, 1904, Two Years After First Treatment.



FIELD OF COTTON A FEW YARDS FROM THE EXPERIMENTAL PLATS.

B. P. I.—163.

IV.—INOCULATION OF SOIL WITH NITROGEN-FIXING BACTERIA.

By A. F. Woods, *Acting Chief of the Bureau of Plant Industry.*

INTRODUCTION.

The publication of the results obtained with pure cultures in inoculating leguminous plants has resulted in a very great demand being made upon the Department of Agriculture for inoculating material. The distribution made during 1904 was for the purpose of obtaining a large number of tests of the method under average farm conditions, and it was impossible to anticipate the demand which has arisen this spring (1905), the total quantity prepared for spring distribution having been promised early in February. It is expected, however, that this fall and next spring a further distribution will be made as far as our limited facilities will permit. Statements to the effect that the Department has stopped the distribution of these cultures are therefore erroneous. Applications for future distributions should state what legume is to be sown, time of sowing, and quantity of seed to be treated.

THE COMMERCIAL PRODUCTION OF CULTURES.

The patent which the Department of Agriculture holds upon the method of growing and distributing these organisms was taken out in such a way that no one can maintain a monopoly of the manufacture of such cultures. It is held in the name of Dr. George T. Moore, who developed and perfected the method, as described in former publications. Upon application the Department furnishes without discrimination all necessary information, and as far as possible "starting" or foundation cultures, to the bacteriologists representing experiment stations and commercial concerns which claim to be properly equipped, but it does not in any way guarantee their product. It is not likely that persons without expert knowledge can successfully multiply cultures of these organisms for sale or distribution, and it is understood that any cultures furnished are to be treated according to the methods devised by the Department.

Before experimenting with any bacterial preparations for legumes, the farmer should study thoroughly the soil conditions under which the use of cultures offers any possibility of gain.[a]

Briefly, these conditions may be summed up as follows:

WHEN INOCULATION IS NECESSARY.

Inoculation is necessary—

(1) On a soil low in organic matter that has not previously borne leguminous crops.

(2) If the legumes previously grown on the same land were devoid of nodules, or "nitrogen knots," showing the need for supplying the nodule-forming bacteria.

(3) When the legume to be sown belongs to a species not closely related to one previously grown on the same soil. For instance, soil in which red clover forms nodules will often fail to produce nodules on alfalfa when sown with alfalfa for the first time.

WHEN INOCULATION MAY PROVE ADVANTAGEOUS.

Inoculation may prove advantageous—

(1) When the soil produces a sickly growth of legumes, even though their roots show some nodules.

If the cultures introduced are of the highest virility, their use will often result in a more vigorous growth.

(2) When a leguminous crop already sown has made a stand, but gives evidence of failing, due to the absence of root nodules.

The use of the culture liquid as a spray or by mixture with soil and top-dressing may save the stand if other conditions are favorable.

WHEN INOCULATION IS UNNECESSARY.

On the other hand, *inoculation is unnecessary and offers little prospect of gain*—

(1) Where the leguminous crops usually grown are producing up to the average and the roots show nodules in normal abundance.

Cultures of nitrogen-fixing bacteria are not to be regarded in the light of fertilizers, increasing yields under all average conditions. They do not contain the nitrogen itself, but the bacteria make it possible for the legumes to secure nitrogen from the air (through the formation of root nodules), and where the soil is already adequately supplied with these bacteria it will not usually pay to practice any form of artificial inoculation.

(2) When the soil is already rich in nitrogen.

It is neither necessary nor profitable to inoculate a soil rich in nitrogen when sowing legumes. Not only does the available nitrogen in the soil render the formation of nodules less necessary, but nitrogenous materials in the soil largely prevent the bacteria from forming nodules.

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[a] Fully described in Farmers' Bulletin No. 214 of the Department of Agriculture, which will be sent without cost upon application to any Senator, Representative, or Delegate in Congress, or to the Secretary of Agriculture.

Any increased virility in nitrogen-fixing power possessed by any types of bacteria yet distributed may be rapidly lost in a soil containing an abundance of nitrogen, because the bacteria are rapidly multiplying in a medium in which there is no premium on vigor in securing atmospheric nitrogen.

WHEN FAILURE IS TO BE EXPECTED.

Inoculation will fail where other conditions (aside from the need of bacteria) are not taken into account, as the following:

(1) In soil that is acid and in need of lime.

Liming to correct acidity is as important for the proper activity of the bacteria as for the growth of the plants.

(2) In soil that responds in a marked way to fertilizers, such as potash, phosphoric acid, or lime.

The activity of the bacteria in securing nitrogen from the air and rendering it available to the legumes does not do away with the need for such fertilizing elements as potash and phosphorus.

(3) It must also be remembered that *inoculation does not "act like magic;"* it will not overcome results due to bad seed, improper preparation and cultivation of ground, and decidedly adverse conditions of weather or climate.

In the use of cultures, also, failure is almost certain where the directions are not carefully studied and intelligently followed.

(4) As the physics, the chemistry, and the biology of soils are studied in the laboratory and by means of actual field-plot trials to determine yield and quality of crops and the effect of one crop on the following crops, the very great complexity of soil and farm management becomes more manifest.

The value of pure-bred bacteria, whether associated with the crop or existing independently in the soil, as is true of fertilizers, can not be predicted with certainty on any soil without trial. Success on similar near-by lands may be taken as good evidence. But, unlike fertilizers, bacteria should in time be so inexpensive that each farmer can afford to try them for each leguminous crop on each field or soil type on his farm. The methods of distributing in dried form and the easy methods of multiplying on the farm in sufficient quantities to inoculate fields will make it possible to have all fields inoculated at all times.

COST OF CULTURES.

The question of the proper price for the commercial product is causing considerable inquiry among prospective experimenters and is of importance. The expenses which a commercial concern must necessarily meet, such as rent, heat, light, insurance, postage, advertising, etc., aside from laboratory assistance and clerical hire, make any comparison with the cost to the Government of similar cultures difficult. The statement that the cultures cost but a few cents an acre refers only to the raw materials which make up the package. It is more than probable that natural competition will considerably reduce the present valuation of the commercial product, and the wisdom of patenting the Department's methods to prevent the formation of a monopoly is already demonstrated.

INCREASING CULTURES.

We are receiving numerous requests from persons who have secured commercial cultures, as well as those sent out from the Department of Agriculture, for information as to the methods employed in producing a large quantity of liquid culture from the dry culture secured as a starter; that is, how to make an "acre culture" do for 25 or 100 acres. Such methods will give good results only when special precautions are taken, and on this account have not been generally recommended. The contaminations, such as yeasts, molds, etc., which are bound to occur to a greater or less extent, are apt to take possession of the culture solution in which the bacteria are being multiplied, and unless great care is taken in thoroughly sterilizing all utensils employed the resulting culture will have no beneficial effect. The extra time required to secure sufficient growth of bacteria in 10 gallons of solution from a dry culture originally intended to produce a 1-gallon liquid culture makes the risk from contamination much greater than where the dry culture is proportioned in size to the larger amount of solution. If a growth sufficient to cloud the solution takes place within two days, the chances of securing an efficient culture are much better than where a longer time is taken; so that the volume of solution prepared should never exceed the actual requirements of the occasion.

The following directions are based on making 10 gallons of liquid culture, sufficient to inoculate 20 bushels of seed. By a litle computation the directions may be adapted to 5 gallons or to any intermediate quantities.

PREPARING AND USING THE CULTURE SOLUTION.

To prepare the culture solution, first select the tub, bucket, or other vessel in which you wish to grow the bacteria. *Clean and scald it out thoroughly.* For making the culture solution, rain water that has been thoroughly boiled and allowed to cool is best, though any good drinking water will answer. Add to 10 gallons of water 12 ounces of either brown or granulated (preferably granulated) sugar, 1½ ounces of potassium phosphate (monobasic), which can be obtained at any drug store, and one-sixteenth ounce (30 grains) of magnesium sulphate. Stir until dissolved, then carefully open the small package containing the bacteria-laden cotton and drop the cotton into the solution. Do not handle any more than is absolutely necessary. Cover the tub with a moist, clean cloth to protect from dust, mold spores, etc. Keep in a warm place, but never let the temperature rise above blood heat. After twenty-four hours add 6 ounces of ammonium phosphate and allow the mixture to stand for another twenty-four hours. The liquid should now be cloudy and ready for use; if sufficient growth has not taken place to bring about this cloudiness, further time should be given, not to exceed a few days.

To inoculate seed.—Use enough culture liquid to moisten the seed thoroughly—about one-half of a gallon per bushel. This inoculating may be done either in a tub or trough, or by sprinkling the culture liquid on the seed on a clean floor and stirring and turning the heaps of seed with shovels until all are thoroughly moistened. After inoculation the seed should be spread out in a clean, shady place until sufficiently dry to handle. If planting is not to be done at once, the seed must be thoroughly dried to prevent molding. In dry weather about 25 bushels can be dried in half a day on 300 square feet of floor space. To do this there must be several open windows or doors to allow a free circulation of air, and the seed must be frequently stirred with a lawn rake. The inoculated seed, if thoroughly dried, may usually be kept without deterioration for several months.

To inoculate soil.—Take enough dry earth or sand so that the solution will merely moisten it. The soil should be preferably from the field to be inoculated, so as to avoid spreading diseases or weeds. Mix thoroughly, so that all the particles of soil are moistened. Thoroughly mix this earth with four or five times as much; spread this inoculated soil thinly and evenly over the prepared ground exactly as if spreading fertilizer. The inoculated soil should be harrowed in immediately to protect the bacteria from sunlight. In using this method allow 1 gallon of the liquid culture to 4 acres or less.

Either of the methods described may be used, as may be most convenient.

To prevent any possible delay, the necessary chemicals should be ordered in advance. If the local druggist does not have them in stock, he can doubtless secure them within a reasonable time.

KEEPING CULTURES FOR FUTURE USE.

The question is frequently arising as to the possibility of the farmer's keeping over cultures from one year to another by soaking up a little of the liquid culture in cotton and drying this cotton. *This pro-*

posed practice is not to be advised in any case. Contaminations take place so readily, and once started spread so rapidly, that for assured good results it is absolutely necessary to start with a pure culture. The pure culture, moreover, can only be prepared by a trained bacteriologist with laboratory facilities. These cultures in the dry state will keep, under ordinary conditions, from six months to a year.

There is an additional reason, fully as important, which makes the above method impracticable. The cultivation of the bacteria for any considerable length of time in solutions containing ammonium salts rapidly lessens their infective power and their ability to gather nitrogen from the air, so that transfers or new cultures made with absorbent cotton from the cultures prepared for field use would contain organisms of reduced efficiency. It is partly owing to these factors that it is impracticable to distribute the bacteria in liquid cultures and maintain the requisite effectiveness.

In the use of cultures for inoculating soil the farmer should be guided, as in all other matters pertaining to soil treatment, by his own peculiar needs, and should not give too great weight to the experiences of others whose soil conditions may differ widely. *It would be unwise to invest largely in any new method for increasing plant growth, whether bacterial or of any other nature, without previously experimenting in a small way.*

DANGER OF INOCULATION BY SOIL TRANSFER.

Satisfactory inoculations have been obtained by transferring soil from old fields on which the legume has been grown, but experience has shown that there are dangers incident to such methods of soil transfer which it is wise to avoid.

The source of supply of such soil should be very definitely known, and in no case should soil be used from fields which have previously borne any crops affected with a fungous disease, a bacterial disease, or with nematodes. Where a rotation of crops is practiced, it is often difficult to make sure of this factor, so that the method of soil transfer is, under average circumstances, open to suspicion, if not to positive objection. Numerous animal and plant parasites live in the soil for years, and are already established in so many localities that it is manifestly unwise to ship soil indiscriminately from one portion of the country to another.

The bacterial diseases of the tomato, potato, and eggplant, and the club-root, brown-rot, and wilt disease of the cabbage, all more or less widely distributed, are readily transmitted in the soil, while in the South and West there are the wilt diseases of cotton, melons, sweet potatoes, cowpeas, and flax, and various nematoid and root-rot diseases which might easily become a serious menace over areas much larger than they now occupy if deliberately spread by the careless use of soil for inoculation purposes. There are several insect and fungous diseases of clover to be avoided, and various diseases of beans and peas. There is also a disease of alfalfa, the "leaf spot," which is causing damage in some regions. These are only a few of many diseases liable to be transmitted in soils. The farmer should therefore be on his guard. The danger from such sources is by no means imaginary. The Department of Agriculture has had specific cases of such accidental distribution reported, and if the business of selling soil for inoculation is made to flourish by farmers purchasing without question "alfalfa soil," "cowpea soil," etc., there is every reason to believe that experience will demonstrate the folly of such haphazard methods.

Of scarcely less importance is the danger of disseminating noxious weeds and insect pests through this plan of inoculation by means of soils. Even though weeds may not have been serious in the first field, the great numbers of dormant seeds requiring but a slight change in surroundings to produce germination are always a menace. The enormous damage to crops caused by introduced insects and weeds should convey a warning and lead to caution. It is not the part of good judgment to view the risk as a slight one justified by the end in view.

PURE-CULTURE INOCULATION.

The extensive experiments carried on by the Department of Agriculture during 1904 demonstrated the fact that, by the proper use of pure cultures, the nodule bacteria are actually carried into the soil in such a way as to form root nodules, and where other conditions are favorable the inoculation thus brought about makes possible the growth of each legume in soils where it had previously failed from the lack of bacteria. The original cultures used, however, must be prepared with the utmost care and with a view to preserving and increasing the natural power of the bacteria as "nitrogen fixers" rather than merely to make them grow under favorable conditions. The methods devised in our Laboratory of Plant Physiology are based on well-recognized principles of plant breeding and selection, and mark a decided advance in the production of cultures for soil inoculation. The old pure-culture methods were not effective, for reasons clearly stated by Doctor Moore in Bulletin No. 71 of the Bureau of Plant Industry and by Doctor Moore and Mr. Robinson in Farmers' Bulletin No. 214.

The Department of Agriculture is continuing the work of developing types of the bacteria associated with leguminous plants, which will have greater activity, collecting from the air more nitrogen per acre than forms now common in nature or available from laboratories. It is desirable that similar investigations should be conducted with reference to the nitrogen-fixing bacteria existing in the soil independent of the legumes. Important steps have already been taken along this line, but the very large demand for cultures for leguminous crops, by consuming the time of the laboratory force, has seriously retarded these investigations during the past year.

The Department is ready to cooperate with experiment stations and commercial firms, to give and to receive suggestions, to test the product of others, and to furnish, as far as possible, cultures to be tested in the laboratory and under field conditions.

There is nothing in the nature of the processes involved which would prevent a competent bacteriologist, after some experience in this particular field, from producing cultures of as high a grade as those sent out by the Department, and every assistance will be given to competent persons desiring to undertake the work.

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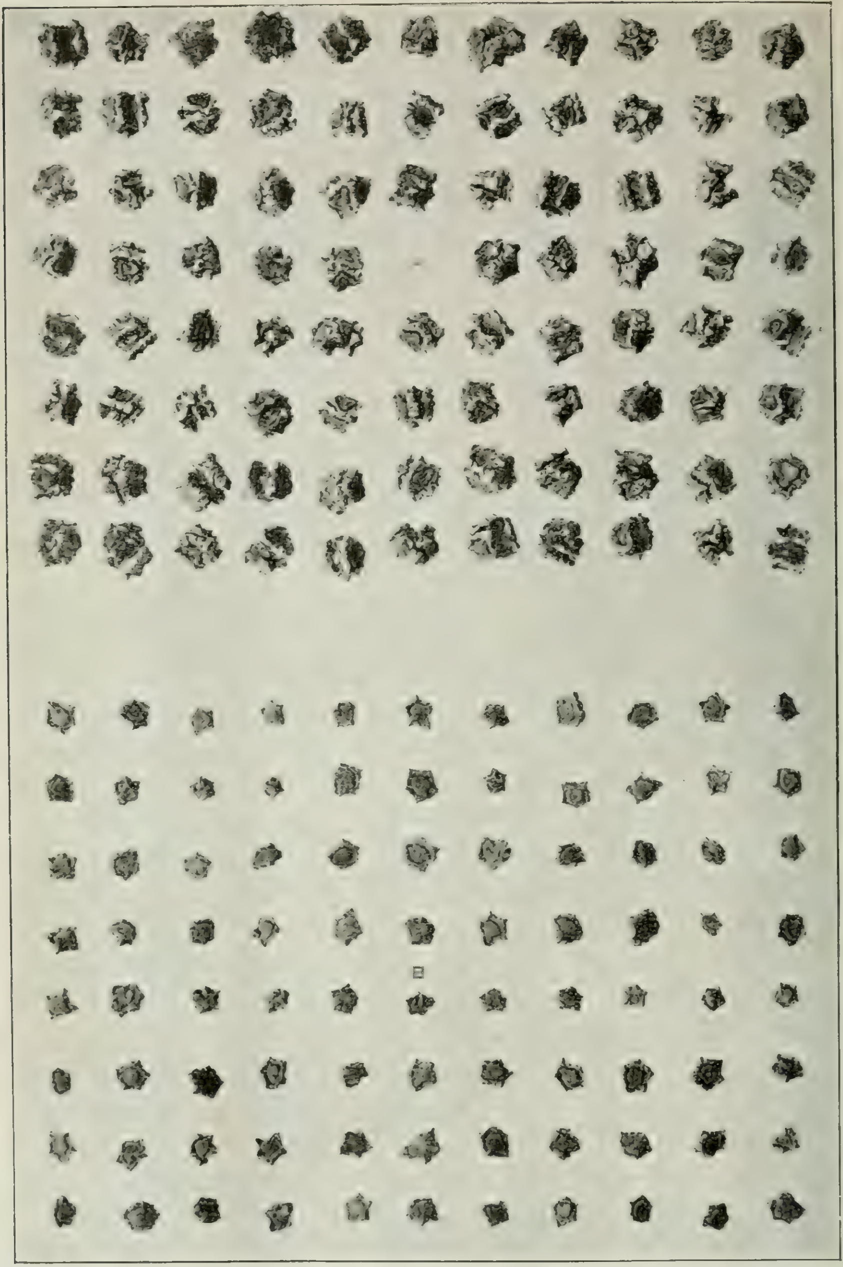

A.—MULTIPLE-GERM BEET-SEED BALLS. B.—SINGLE-GERM BEET SEEDS.

Natural size.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 73.

B. T. GALLOWAY, *Chief of Bureau.*

THE DEVELOPMENT OF SINGLE-GERM BEET SEED.

BY

C. O. TOWNSEND, Pathologist,

AND

E. C. RITTUE, Assistant.

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS.

Issued March 25, 1905.

239384
13. 1.30

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

BUREAU OF PLANT INDUSTRY.

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Pathologist and Physiologist, and Chief of Bureau.

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[a] Detailed to the Bureau of Forestry.
[b] Detailed to Seed and Plant Introduction and Distribution.
[c] Detailed to Botanical Investigations and Experiments.
[d] Detailed to Bureau of Chemistry.
[e] Detailed from Bureau of Chemistry.

LETTER OF TRANSMITTAL.

U. S. DEPARMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY,
OFFICE OF THE CHIEF,
Washington, D. C., January 26, 1905.

SIR: I have the honor to transmit herewith the manuscript of a paper submitted by the Pathologist and Physiologist, entitled "The Development of Single-Germ Beet Seed," by Dr. C. O. Townsend, Pathologist in Charge of Sugar-Beet Investigations, and Mr. E. C. Rittue, Assistant, Vegetable Pathological and Physiological Investigations, and recommend its publication as Bulletin No. 73 of the series of this Bureau.

The accompanying eight plates are necessary to a clear understanding of the subject treated in the text.

Respectfully,

B. T. GALLOWAY,
Chief of Bureau.

HON. JAMES WILSON,
Secretary of Agriculture.

PREFACE.

Efforts to produce a single-germ beet seed have created considerable interest among sugar-beet growers, and numerous inquiries have been received in regard to the progress of the undertaking. It has been considered advisable, therefore, to present at this time a preliminary report relative to this work, giving a brief description of the sugar-beet flower, single and multiple germ seed balls, and the methods employed in carrying the work forward from its inception two years ago until the present time.

It is encouraging to know that some progress has been made toward the solution of this problem and undoubtedly it is only a question of time when beets will be grown commercially from single-germ seed.

Acknowledgment is hereby made to Mr. T. R. Cutler, manager; Hon. George Austin, general agricultural superintendent, and Mr. Parley Austin, local agriculturist for the Utah Sugar Company, for their assistance in carrying forward this work.

A. F. Woods,
Pathologist and Physiologist.

Office of Vegetable Pathological
and Physiological Investigations,
Washington, D. C., January 20, 1905.

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THE DEVELOPMENT OF SINGLE-GERM BEET SEED.

INTRODUCTION.

Owing to the importance that the beet-sugar industry has attained in the United States, and to the possibilities of the extension of sugar-beet growing and beet-sugar production in this country, it is desirable that every effort be made to improve to the fullest extent the quality of the beets and to cheapen in every way possible the cultural processes involved in sugar-beet growing, so that the largest returns per acre may be obtained at a minimum cost. The first part of this proposition—the improvement of the quality of the beet—depends to a large extent upon the proper selection of beets for seed production, upon improved methods of cultivation, and upon the proper relation of the plant to soil and climate. The second part of the proposition—the cheapening of the cultural processes relating to sugar beets—may be accomplished either by skill acquired by practice in performing the various hand operations so that a greater amount of work of a given kind may be done in a definite time, or by the employment of labor-saving machinery, or by so changing the beet or the seed that certain operations are no longer necessary.

The Department of Agriculture has in view the accomplishment of the improvements above outlined, and it is believed that the production of single-germ beet seeds on a commercial scale will do much toward reducing the cost of sugar-beet production, and will possibly improve the quality of the beets in one or more directions. It is the purpose of this preliminary report to show to those interested in the subject the progress that has been made in the development of a single-germ beet seed during the two seasons that the work has been under way.

Mr. Truman G. Palmer, secretary of the Beet Sugar Manufacturers' Association, in a contribution to the annual report on the progress of the beet-sugar industry in the United States[a] discusses the advantages and disadvantages that would result from the use of single-germ beet seeds, and while the obstacles in the way of employing single-germ seeds on a commercial scale are of sufficient importance to demand consideration, there is no reason to suppose that these obstacles can not be overcome, as Mr. Palmer has suggested. At any rate, the only satisfactory way to determine the practicability of the single-germ seed for beet production is to produce such seed in sufficient quantity so that it can be tested on a commercial scale in comparison with multiple-seed balls under the same conditions of soil and climate.

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[a] See Progress of the Beet-Sugar Industry in the United States in 1902.—Report No. 74, United States Department of Agriculture, pp. 141–152.

SINGLE AND MULTIPLE GERM BEET SEED.

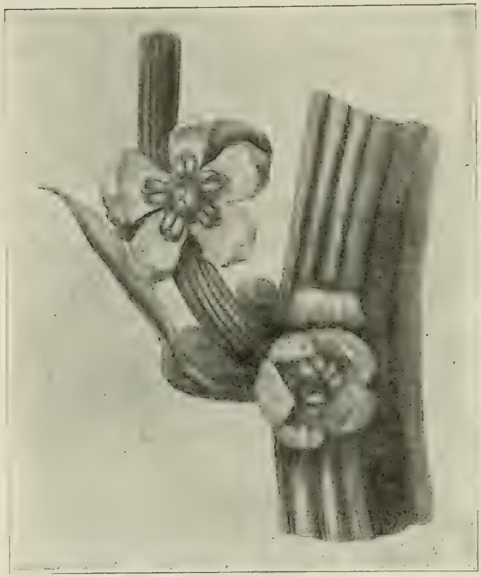

FIG. 1.—Clusters of closed and partly open beet flowers.

The term "seed ball," as applied to beet seeds, implies a combination of seeds into a mass having a more or less rounded appearance (Pl. I, A); hence, the term "ball" can not properly be applied to the single-germ beet seed (Pl. I, B). Each germ arises from a single floret, and when the flowers are in clusters of two or more (fig. 1) a multiple-germ seed arises; whereas, if the flower stands by itself on the stem (fig. 2) a single-germ seed results. If two or more single flowers stand very close together but do not arise from the same point as in the case of flower clusters, each will produce a single-germ seed (Pl. II). Even if the flowers are so close together that the seeds slightly adhere in the process of development, they are easily separated and readily distinguished as single-germ seeds (Pl. III, flower stalk on right hand, end of second branch at left). On the other hand, the component parts of a multiple-germ seed ball adhere so firmly that they can not be separated by any known process without great danger of injuring the germs. It appears, therefore, that the arrangement and distribution of the flowers on the seed stalk determine whether the seeds are to be single-germ seeds or whether they are to be parts of multiple-seed balls. One can determine in practically all cases, even before the flowers are open, whether they will produce single-germ seeds or whether they will be parts of a multiple-seed ball.

A typical single-germ beet seed is a five-pointed star possessing a somewhat flattened appearance (Pl. I, B). As a rule, these are easily distinguished from the multiple-germ seed balls, as shown in Plate I, A. Frequently the points of the star are broken off, when a more careful examination is necessary to determine whether the seed in question contains one or more germs. A close examination of a number of these seeds and a comparison of them with multiple seeds will soon make the selection of single-germ seeds comparatively easy.

There is a false single-germ seed against which it is necessary to guard in making selection of the single-germ seeds. This false single-germ seed arises usually from what would have been a double-germ seed (Pl. VIII, fig. 2) had not one of the seeds failed to develop. A more or less close examination will invariably enable one to determine which is the false and which is the true single-germ seed.

The careless observer often makes the mistake of supposing that the small seeds are all single germs and that all multiple seed-balls are large. Some seedsmen have made the assertion that 60 per cent of the seeds produced by beets have single germs and that these seeds are sifted out and discarded from the commercial seed. The writers obtained a sack of the siftings from a quantity of commercial beet seed, as they had been informed that these siftings were composed of nearly all single-germ seeds. A careful examination of this seed was made and the different sizes were separated by means of sieves having 6, 8, 10, 12, and 14 meshes per inch. (See Pl. IV, B to G.) The results are tabulated for convenience to show the percentage of singles that were caught in each sieve, while in Plate IV the percentage of single-germ seed is roughly indicated by the number of singles at the end of the second row in each set. (See Table I, p. 12.) A study of this table shows how erroneous is the common impression with reference to the number of single-germ seeds that are present in commercial seed. Many of the single-germ seeds are larger than many of the multiple-germ seeds, as shown by Plate IV, D, compared with singles shown in groups A, B, and C. In practically all commercial seeds there are a few single-germ seeds, but an examination of a large quantity of commercial seed and a study of many seed beets in the field show that the number of singles produced by the ordinary beet-seed plant is very small. (See Table III, p. 22.)

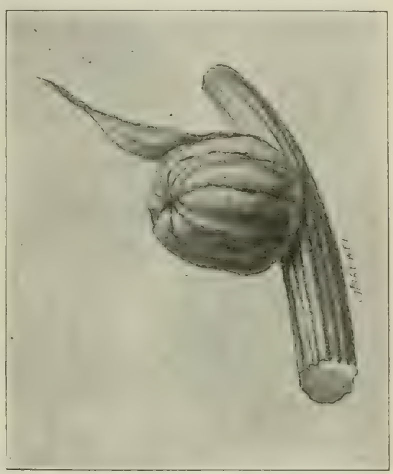

FIG. 2 —A single beet flower bud.

TABLE I.—*Percentage of single-germ seeds from siftings.*

	Number of meshes per inch.				
	6	8	10	12	14
Percentage of single germs	3	8.8	8.8	8.5	7.6

The singles that remained in sieves of 6 and 8 meshes to the inch were of normal size and well filled; those that remained in the sieve of 10 meshes were small but well filled; those left in the 12 and 14 mesh sieves were to a great extent not filled at all, while others were simply immature flowers, and, taken all together, they constituted but the small percentage of 7.34—considerably less than 8 per cent. While we have no way of determining what bulk of the cleaned seed these siftings represent, study of seeds obtained from ordinary beet plants leads to the conclusion that they do not represent more than one twenty-fifth, or 4 per cent, of the original bulk. If this be true, and on an average three seeds from the siftings are equal in weight and bulk to one commercial seed, the following conclusions can be reached:

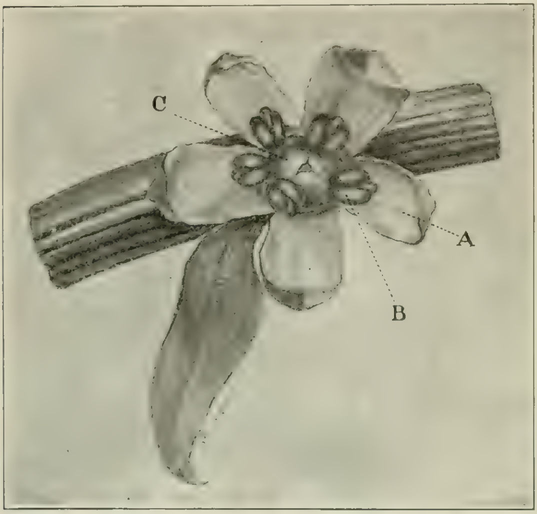

FIG. 3.—A single beet flower. A, sepal; B, anther; C, pistil.

Percentage of singles in siftings 7.34÷8⅓ (25÷3)	0.88
Percentage of singles in commercial seed	.96
Average percentage of singles in ordinary seed	1.84

This is somewhat lower than the percentage of singles on the plants selected from the field of ordinary seed beets. (See the second column of Table III, p. 22.) It must be remembered that the 2.77 per cent given in Table III is the average of singles on the ten best plants and not the average of all the plants in the field.

THE BEET FLOWER.

The beet flower consists of three sets of organs arranged in three whorls (fig. 3). The outer set is composed of five green parts, called sepals (fig. 3, A), which are attached to and form a part of the seed coat. In the early stages of the flower, i. e., before it opens, these five sepals inclose and protect the other parts of the flower (fig. 4).

These sepals are not united with each other along the edges except near the base, so that when the flower opens they form a five-pointed star (fig. 3). It is these five sepals which form the five points of the star when the seed is ripe (Pl. VIII, fig. 4). These parts, as well as the remainder of the seed coats, turn brown upon the ripening of the seeds. The second set of organs consists of five stamens, one opposite each sepal (fig. 3, B). Each stamen consists of a fine stalk, called a filament (fig. 5, D), and on the free end of each filament is a sack, called an anther (fig. 3, B, and fig. 5, B). The anthers contain the pollen grains, a few of which much enlarged are shown in figure 6. There are thousands of pollen grains produced in each anther, and as there are five anthers in each flower the pollen grains produced by each flower are almost innumerable, and when we consider that each plant produces thousands of flowers we can readily understand how it is that the air in and around a field of seed beets at flowering time is filled with these grains.

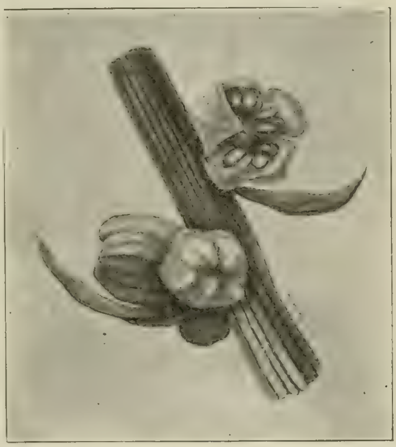

Fig. 4.—A single beet flower and a cluster of buds.

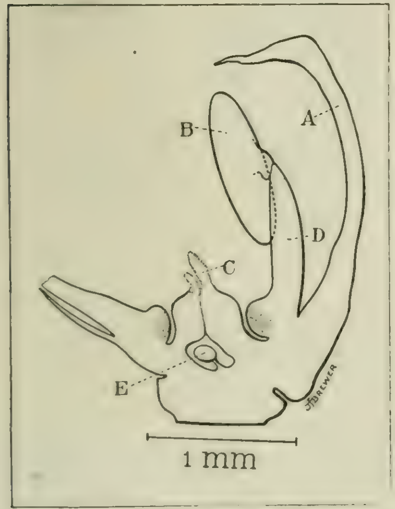

Fig. 5.—Section of a beet flower. A, sepal; B, anther; C, pistil; D, filament; E, seed germ.

The third set of flower parts is in the center of the flower, and is called the pistil or pistils (fig. 3, C, and fig. 5, C). In the beet flower the pistil is composed of three parts, as shown in figure 3, C. Just at the time the flowers are ready to open completely, the pollen grains become ripe, i. e., they reach a stage of development when under proper conditions of warmth and moisture they will produce what are called pollen tubes. At this stage of the development of the pollen grains the anthers burst, allowing the grains to escape. At the same time the three-parted pistil becomes sticky and some of the pollen grains, carried either by the wind or by some other agency, such as insects, fall upon the pistil and remain attached. This transfer of pollen from the anthers to the pistil is the process known as pollination. Under the favorable conditions already mentioned pollen tubes are produced and grow down into the lower part of the pistil, where the contents of a pollen tube unite with the contents of the lower part of the pistil to form the germ which is destined to produce the new plant (fig. 5, E). This union of the contents of the pollen tube and of the lower part of the pistil is called fertilization.

This brief description of the flower parts and their function will, it is hoped, serve to make clear the terms pollination and fertilization, without some knowledge of which the methods employed in our flower selection and treatment would be meaningless. It should be clearly understood that it is through the union of the contents of a pollen tube with the contents of the lower part of a pistil that the germ which is to produce the new plant is formed. The pollen grain thus utilized may originate in the same flower which it fertilizes, or it may originate in one flower and be transferred by some agency to the pistil of another flower. In the former case we speak of this process as close-pollination or close-fertilization, as the case may be, while in the latter case we speak of it as cross-pollination or cross-fertilization.

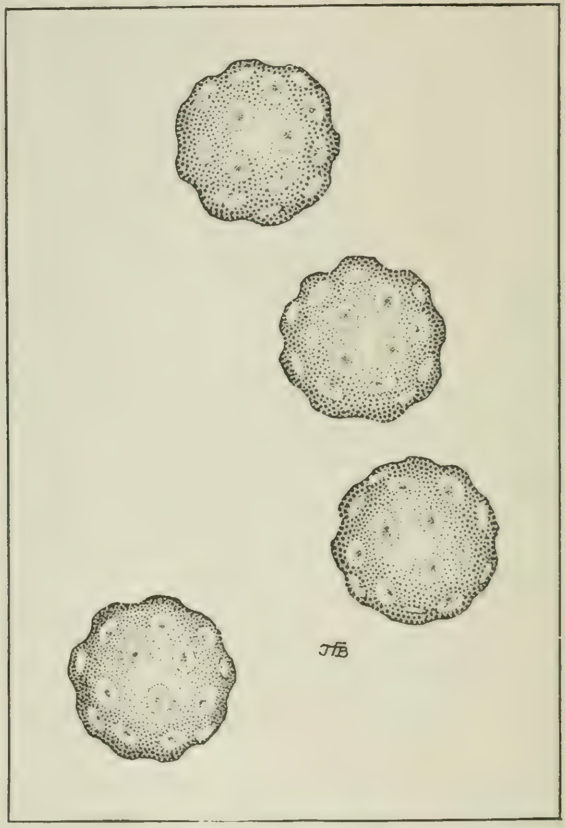

FIG. 6.—Pollen grains. × 750.

THE FIRST SEED SELECTION.

As soon as the work of producing single-germ beet seed was taken up, the various methods by which the desired results might be reached were considered and the writers arrived at the conclusion that the most satisfactory results could be attained by the production of a plant that should bear only single-germ seeds rather than by any process which should have for its aim the separation of the multiple-germ balls into the several seeds of which they are composed. Accordingly, samples of about 4 pounds each of eight of the leading varieties of commercial sugar-beet seeds were obtained, and all the single-germ seeds were carefully separated from the multiple-germ seeds in these samples. The single and multiple germ seeds were counted and the percentage of singles computed, whereupon it was found that the number of single-germ seeds consisted of a little less than 1 per cent (0.96) of the entire number of seeds in the 32 pounds examined. This calculation does not determine the percentage of single-germ seeds produced by beets of different varieties, but serves to show the percentage of single-germ seeds that are present in our ordinary commercial seed of the first grade. Subsequent selections and calculations along the same line served to confirm the results given above. The first single-germ seeds selected were used for two purposes: (1) For comparison in regard to germination and vitality with multiple-germ seeds, and (2) for the production of seed beets in the greenhouse, with the hope of gaining one season toward the solution of the problem of single-germ seed production.

GERMINATION AND VITALITY.

A comparison of the germination and vitality of single-germ seeds as compared with multiple-germ seeds is best brought out by means of Table II, which shows a distinct difference in favor of the single germ seeds.

Table II.—*Comparison of germination.*

Kind of seeds used.	Number of seeds used.	Number of germs in seeds used.	Date of planting.	Number of seedlings produced each 24 hours after planting for 10 days.										Total number of seedlings.	Percentage of germination
			1903.												
Single-germ seeds..	400	400	Mar. 26	0	0	6	32	73	94	76	31	10	7	329	82
Multiple-germ seeds	100	400	....do...	0	0	0	5	9	27	29	70	37	12	199	49

The seedlings from the multiple-germ seeds were thinned as carefully as possible, but the difference in growth was distinctly in favor of the plants produced from the single-germ seeds, and this difference held good during the growth of the plants. Further experiments of this kind confirmed the results shown in the table, viz, that the single-germ seeds sprout in a shorter time than the seeds in the multiple balls; that the percentage of germination is higher, and that the plants produced from the single-germ seeds possess greater vitality than those produced from multiple-seed balls. The single and multiple germ seeds used in these comparative experiments were taken from the same lot of commercial seeds.

GREENHOUSE EXPERIMENTS.

Several hundred plants from single-germ seeds were started in the greenhouse in December, 1903, with the hope of obtaining a crop of seed the following summer. The plants made a luxuriant growth and, when they had attained a weight of from 1 to 2 pounds, water was withheld and the beets were left to ripen. After two weeks of ripening, nearly all the beets were taken up and siloed. At intervals of several weeks some of the siloed beets were replanted, but the results were uniformly negative, so far as the production of seed stalks is concerned. Etherizing and other methods of inducing the plants to produce seed stalks were resorted to, but likewise with negative results. It was therefore necessary to depend upon field planting for the first crop of seed beets.[a]

SEED BEETS IN 1903.

In the spring of 1903, about four thousand single-germ seeds were selected from commercial seed of different varieties and planted on the Arlington Experimental Farm of the Department of Agriculture. Previous to planting, the seeds were photographed in natural size (Pl. I, B), and each seed was given a number which corresponded to the number given the plant after it came up. The rows in which the seeds were planted were 20 inches apart and the seeds were dropped and covered by hand at intervals of about 10 inches in the row. Conditions for germination were favorable and fully 90 per cent of the seeds germinated. Beets grown for another purpose in the same field from multiple-germ seeds were planted with a hill dropper. The stand in both cases was about the same, but the additional labor necessary to hand-thin the seedlings from the multiple-germ seeds was in marked contrast to the rows planted with the single-germ seeds, where no hand-thinning was required.

In actual practice it is not proposed to plant the single-germ seeds at intervals of 8 or 10 inches, but rather 2 or 3 inches apart, so that those not desired can be cut out with a hoe, and the planting will be done by the aid of a planter and not by hand. In the experimental plat it was desired to give every beet the best possible chance to develop without destroying any of the plants. Unfortunately for the experiment, a part of the ground where the single-germ seeds were planted had been previously scalped, i. e., the sod had been removed and with it practically all the fertile soil. The natural result was that the seeds planted on this spot merely germinated and the seedlings died from starvation. As this poor strip of ground extended across one end of the rows only, most of the plants from each variety used came to maturity. At the close of the season about one thousand beets grown from the single-germ seeds were selected and siloed for the next season's seed production.

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[a] The term "mother beet," commonly applied to beets used for seed production, implies that the beet flowers borne on the seed stalks possess only female organs, while, as a matter fact, each flower bears both the male and the female organs, as shown in figure 3, page 12. It is therefore suggested that in the place of the expression "mother beet" the more accurate and simple term "seed beet" be used.

BEET SEED IN 1903.

Since the production of sugar-beet seed had not been previously undertaken on the Arlington Farm, it was considered advisable to plant a few seed beets in the spring of 1903, in order to be better prepared to deal with the first crop of seed beets from single-germ seeds during the season of inflorescence in 1904. The two principal objects in growing the trial lot of seed beets were (1) to determine whether or not beet seed could be grown in this locality, and (2) to give an opportunity for studying the arrangement of the single and multiple flowers and their distribution on the flower stalks.

Accordingly a number of seed beets were obtained from the New York Experiment Station at Geneva, through the kindness of Professor Churchill. These beets were received at Washington in good condition and were planted on the Arlington Farm. Practically all of them developed seed stalks, flowers were produced in great abundance, the patch swarmed with insects during the flowering season, and the weather seemed to be all that could be desired for the proper pollination and fertilization of the flowers; but when the seed was ripe it was found upon close examination that less than 5 per cent of the hulls contained germs. Plate V shows two types of the seed stalks produced. For some reason the seeds had failed to fill, and it was considered inadvisable to undertake an experiment that depended for its success upon seed production in a locality where the probabilities were that only a very small percentage of the seeds would fill, even under the most favorable conditions. However, the flowers that were produced upon these plants enabled us to study their arrangement and to consider the methods best suited to the accomplishment of seed selection.

The first of these plants to bloom (Pl. V, plant on right hand) showed flowers thirty-one days after planting, and produced nearly all two-seeded balls, the exceptions being a few single-germ seeds which were formed at the intersection of the spikes (Pl. II), and near the tips of the spikelets. In fact, this arrangement prevailed in all the plants, as follows: On all spikes that bore two-seeded balls there were found at the bases of most of the spikelets a two-seeded ball on one side at the intersection and a single-germ seed on the other side (Pl. II), and later in the season when these spikelets were farther advanced numerous single-germ seeds formed throughout the limb, while in a few instances the tips were thickly studded with singles for several inches. But these flowers seldom produced seeds, as they developed too late in the season. The spikes that bore multiples of 4 or 5 seeded balls seldom produced singles even at the bases of the spikelets, but the spikelets invariably produced balls of fewer seeds than were found on the main spike. If the spikelets again divided, double-seeded balls and single-germ seeds were found at the bases and sometimes at the tips of these secondary spikelets.

CHANGE OF LOCATION OF EXPERIMENTS.

As soon as it was found that the production of sugar-beet seed in the vicinity of the District of Columbia was very uncertain it became essential to select a suitable location for the continuation of the work. At this time it became necessary for one of the writers to visit a large number of the sugar-beet sections in connection with some other beet work, and while in Utah he learned that sugar-beet seed had been grown by the Utah Sugar Company at Lehi for nine consecutive years without even a partial failure, and that each succeeding year the area had been increased with good results. This company very cordially invited the Department of Agriculture to conduct its single-germ beet-seed work and such other sugar-beet experiments as it might see fit to make on one of its farms located near the outlet of Lake Utah. The soil there is a deep rich loam and is irrigated from warm springs which supply an abundance of water. The conditions thus offered for the growth of sugar beets and for the development of sugar-beet seed seemed to be all that could be desired, and the invitation to locate the experiments at this point was gladly accepted. The results obtained indicate that no mistake was made in the selection of this location for the continuation of the sugar-beet work.

PROGRESS OF THE WORK IN 1904.

PLANTING AND GROWTH OF THE SEED BEETS.

In April, 1904, several hundred seed beets were shipped to Lehi and carefully planted under the supervision of the Utah Sugar Company's experienced agriculturist, Hon. George Austin. Only two of the plants that were set out failed to live and less than 1 per cent failed to produce seed stalks. The beets were planted in rows 3 feet apart and the space between the plants was 3 feet. The seed stalks were numerous, strong, and well supplied with flowers that eventually developed well-filled seeds. Early in June the writers were notified, in accordance with a previous arrangement, that the flowers were nearly ready to open. Accordingly, they left at once for Lehi, where the flowers were found in the best possible condition for the work.

ARRANGEMENT OF SINGLE FLOWERS.

The writers had previously learned that the single and multiple flowers were distributed over the seed stalks with more or less regularity (Pl. III). As a rule the single flowers destined to produce single-germ seeds were located at the joints, i. e., at the points on the stem where the branching takes place. That there is a great difference in seed stalks with reference to the number of branches produced is shown in Plate V, which illustrates some of the types of seed stalks found in fields of commercial seed. It is evident that the seed stalks shown in the plant on the right-hand side of this plate are much more frequently branched than are those shown in the plant on the left-hand side, and consequently have more points at which single-germ seeds would naturally form. However, if single-germ seeds were produced only at the bases of the branches the total number would be small compared with the number of seed balls produced on the ordinary seed stalks.

Not infrequently on the commercial beet-seed stalks single flowers are found, and later single-germ seeds extending out on the branches, even to the tips. This arrangement of the single-germ seeds along the sides of the seed stalks was found to be still more common on the seed stalks produced by beets grown from single-germ seeds (Pl. III). This is an encouraging indication of the possibility of a plant producing single-germ seeds on all the branches throughout their entire length, in which case we would have a plant producing only single-germ seeds and at the same time bearing seed in commercial quantity.

METHODS OF POLLINATION.

It is entirely possible for single flowers to be cross-fertilized with pollen from flower clusters in the natural process of fertilization. This would give to the plant produced from the single-germ seed a tendency to produce flower clusters and consequently multiple-germ seeds. In order to avoid the danger of contaminating the single flowers which were selected for seed production with the pollen of multiple-germ seeds all multiple flowers were carefully trimmed away before they were open and before the single flowers which were left on the stalks had opened. Plate VI, figure 1, shows one of the selected plants after the multiple flowers were removed.

In order to prevent the single flowers from receiving the pollen that might be floating in the air from other plants, they were covered with paper bags, as shown in Plate VI, figure 2. If it was desired to cross-fertilize the single flowers they were carefully opened by means of a needle or scalpel, the anthers removed before the pollen was ripe, and they were then covered with the paper bags. It was necessary to uncover the flowers from time to time to see when the pistil was ready to receive the pollen.

To protect the flowers at such times against stray pollen that might be floating in the air the operator covered himself and the plant that he was pollinating with a cloth tent. This tent was supported by an iron rod fastened to the back of the operator. Plate VII, figure 1, shows one of the tents as it is being placed in position and Plate VII, figure 2, shows the tent in position. When the pistil was in condition to receive the pollen it was pollinated by means of a camel's-hair brush and the paper bag was again placed over the pollinated flower. This operation was carried on under the cloth tent.

If close-fertilization was desired, each flower to be pollinated was covered with a paper bag and the anthers were not removed, since it was desired that the pistil should receive the pollen from the same flower. The same precautions were taken in excluding other pollen as in the preceding case.

Another method, which, for want of a better term, may be called "bunch pollination," consisted in covering the single flowers with paper bags, inclosing several flowers in the same bag and not removing any of the anthers. When the pollen became ripe it was set free from the anthers but could not escape from the bag. An occasional shaking of these flower stalks caused the pollen to lodge upon the pistils, and thus the flowers were pollinated. It was certain by this process that the flowers, which were in all cases covered with the bags before any of them opened, were pollinated with pollen from single flowers only and from the same plant upon which the seed was to be produced, but it was not possible to determine whether a flower had been pollinated with its own pollen or with that from another flower on the same stalk. However, the process is much more rapid than either the cross-pollination or self-pollination previously described.

By utilizing these various methods of pollination, about 15,000 single flowers, produced by 50 of the plants that possessed the highest number of single flowers, were treated. It was impossible to cut away the multiple flowers on any plant without removing some of the single flowers; hence, the 15,000 flowers treated do not represent the total number of single flowers on these plants.

After the flowers were treated and covered with the paper bags, the plants were protected from the wind, so that the paper bags would not be blown off, by covering the entire plant with a cloth bag made for this purpose. These bags were supported by four strong stakes driven into the ground until they were firm. The number of flowers handled was limited by the progress they made in opening; i. e., as soon as the flowers opened so that there was danger of pollination taking place before they were covered with the paper bags, it was necessary to abandon the work. The period that elapsed from the time the buds were large enough to work until the flowers had opened so that further work was impossible was about three weeks—from June 15 to July 4.

It was now necessary simply to go over these 50 plants from time to time and remove the superfluous growth that was forced from the nodes as a consequence of the excessive trimming due to removing the multiple flowers and the branches that bore them. As soon as the seeds had set, the paper bags were removed, but the plants were still protected by the cloth bags, which remained over the plants until the seed ripened.

GATHERING THE SEED.

Early in August the seed was ready to be gathered, and that from each of the 50 plants was kept separate and a record made of the plant from which it was obtained. The seeds were also kept separate with reference to the method of pollination. Of the 15,000 single flowers treated, about 10,000 set their seed and reached maturity. These will be carefully planted by hand at the proper time for the production of the second crop of seed beets, from which the writers hope to obtain their second crop of seeds. These single-germ seeds are larger than similar seeds that were selected for the first planting, as shown in Plate VIII, figure 4. Plate VIII shows the comparative sizes of multiple seed balls (fig. 1), double seed balls (fig. 2), and single seeds from the same plant (figs. 3 and 4). The larger growth of the seeds shown in figure 4 is probably due in some measure to the trimming that the branch that bore these seeds received, thus throwing more of the growth and vigor of this branch into the seed.

PERCENTAGE OF SINGLE-GERM SEEDS.

As already indicated, 50 of the plants that possessed the highest number of singles were selected for the special pollination work. Owing to the method of treatment already described, it was impossible to determine the percentage of single flowers on the 50 plants that were treated. As a consequence, it is impossible to compare accurately the number of single-germ seeds produced by these 50 plants grown from single-germ seeds with the number of singles produced by plants grown from commercial seed. However, after selecting the 50 plants for this work, 20 of the plants remaining that showed the highest percentage of singles were picked out and all the seeds from each plant were carefully saved and kept separate. From a field of 17 acres of beet seed, in which the seed beets were produced from ordinary commercial seed, 10 plants that showed the highest yield of single-germ seed were also selected for comparison. The seed from each of these plants was kept separate and all the seed of each plant was carefully saved. These results are embodied in the following table, together with the results previously mentioned in regard to the percentage of singles in commercial seed and in siftings:

TABLE III.—*Comparison of percentages of single and multiple germ seeds from selected plants, from siftings, and from commercial seed.*

From seed beets grown from single-germ seed.	From field of ordinary beet seed.	From siftings.	From commercial beet seed.
0.25	0.018	....	....
.212	.047	....	....
.21	.018	....	....
.145	.028	....	....
.122	.029	....	....
.114	.046	....	....
.105	.037	....	....
.098	.011	....	....
.092	.015	....	....
.082	.021	....	....
Av..0.143	0.027	0.0734	0.0096

It will be seen from this table that the best plant—i. e., the one possessing the highest number of single-germ seeds that could be found in a field of 17 acres grown from commercial seed—bore 4.7 per cent of single-germ seed, or a little less than one-twentieth, of all the seeds produced by the plant, and the average for the ten selected plants was less than one thirty-fifth of all the seed produced by the plants.[a] On the other hand, the number of single-germ seeds produced by the next best plant after 50 of the best ones had been selected—i. e., from the fifty-first plant—in point of number of singles was 25 per cent, or one-fourth of all the seed produced by the plant, and the average for the ten plants, ranging from the fifty-first to the sixtieth best, was a little less than one-seventh of the seed produced by the 10 plants.

It is true that out of the total number of plants grown from single-germ seeds and used in this selection work a large number of them produced in point of numbers, so far as could be determined by casual observation, approximately the same quantity of single-germ seeds that were produced by beets grown from ordinary multiple-germ seed. It must be remembered, however, that all the seeds with which the first planting was made were selected from commercial seed, so that nothing is known in regard to the plants or the manner of the pollination of the flowers that produced the seeds. It would not be surprising if a large number of the single-germ seeds found in commercial seed were produced from flowers which were pollinated and fertilized by pollen from flower clusters instead of from single flowers.

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[a] It should be noted that this proportion represents selected plants and does not show the percentage of single-germ seeds grown on ordinary plants taken at random, which would be somewhat less than one thirty-fifth.

CONCLUSION.

It is the purpose of those having this work in charge to continue their experiments along the same line during the coming season. The writers expect to produce this year a crop of seed beets from their selected single germ seed and to silo these beets in the autumn for next year's seed production. Meantime the experiments of last year will be repeated. In addition to this repetition, serving as a comparison of the results already obtained, it will give this season a crop of seed similar to the seed saved last year. The importance of this precaution appears when it is remembered that it takes two years to produce a crop of seed, and that any accident to the present supply of seed would cause a delay of two years unless a quantity of seed beets ready to produce more seed was on hand. For this reason it is planned to repeat each year the experiments of the preceding season.

As soon as a sufficient quantity of single-germ seed has been produced, the writers hope to conduct comparative experiments with single and multiple germ seeds in different localities to determine the influence of soil and climate upon beet production from single-germ seed and to test the practicability of using single-germ beet seed on a commercial scale. Further reports, showing the progress of the work, which must necessarily extend over a considerable period, will be published from time to time.

PLATES.

DESCRIPTION OF PLATES.

Plate I. A.—Typical multiple-germ beet seeds, showing some of the variations in shape and size of commercial sugar-beet seed balls. Natural size. B.—Single-germ beet seeds selected from commercial seed, showing some of the variations in shape and size. Natural size.

Plate II. Upper part of flower stalk from beet plant, showing method of branching, and also size and arrangement of flowers, both single and in clusters. Natural size.

Plate III. Flower stalks from which the flower clusters have been removed, leaving only the single flowers. The branch at the right is the same as that shown in Plate II. Some of the flowers on the branch are already open; hence too late to bag for hand pollination. The branch at the left has all the flowers still closed, and is ready to bag. Some of the single flowers stand close together, as shown at the top of branch at the left, so that in the cut they appear like doubles. Natural size.

Plate IV. Different grades or sizes of sugar-beet seed obtained by taking commercial seed as shown in *A* and by separating the so-called siftings into the grades *B*, *C*, *D*, *E*, *F*, and *G*, by means of sieves having 6, 8, 10, 12, and 14 meshes per inch, respectively. *F* shows the material too coarse to pass through the sieve having 14 meshes per inch, and *G* shows the material that passed through the sieve. *B* and *C* are good grades of small seed. *D* contains a large amount of seed not filled. *E* and *F* contain only a few seeds that are filled, and numerous immature florets. *G* is composed mostly of broken florets, leaves, and stems. An attempt is made in each case to represent the percentage of singles. This can be done only approximately. The percentage in *A* is nearly 1; in *B*, 3; in *C*, 8+, in *D*, 8+, and in *F*, 8—; so that for 25 seeds the percentage of single seeds is only approximately correct.

Plate V. Two types of beet-seed stalks. The one at the right is much more branched than the one at the left and possesses many more single-germ seeds.

Plate VI. Fig. 1.—Flower stalks with multiple flowers removed, leaving only the singles ready to be bagged for hand pollination. Fig. 2.—Single flowers covered with paper bags to protect them from foreign pollen.

Plate VII. Fig. 1. Cloth tent being adjusted to cover the operator and the plant upon which he is to work. Fig. 2.—Tent in position, covering the operator and plant in order to protect the flowers from foreign pollen.

Plate VIII. Various forms of sugar-beet seed. Fig. 1.—Multiple beet-seed balls obtained from a selected plant grown from single-germ seed. Natural size. Fig. 2.—Double beet-seed balls from the same plant. Natural size. Fig. 3.—Single-germ beet seed from a branch of the same plant, not trimmed and not hand pollinated. Natural size. Fig. 4.—Single-germ beet seed from a branch of the same plant that was trimmed and hand pollinated. The larger size may be due to the trimming away of the multiples, or to the hand pollination, or to both. Natural size.

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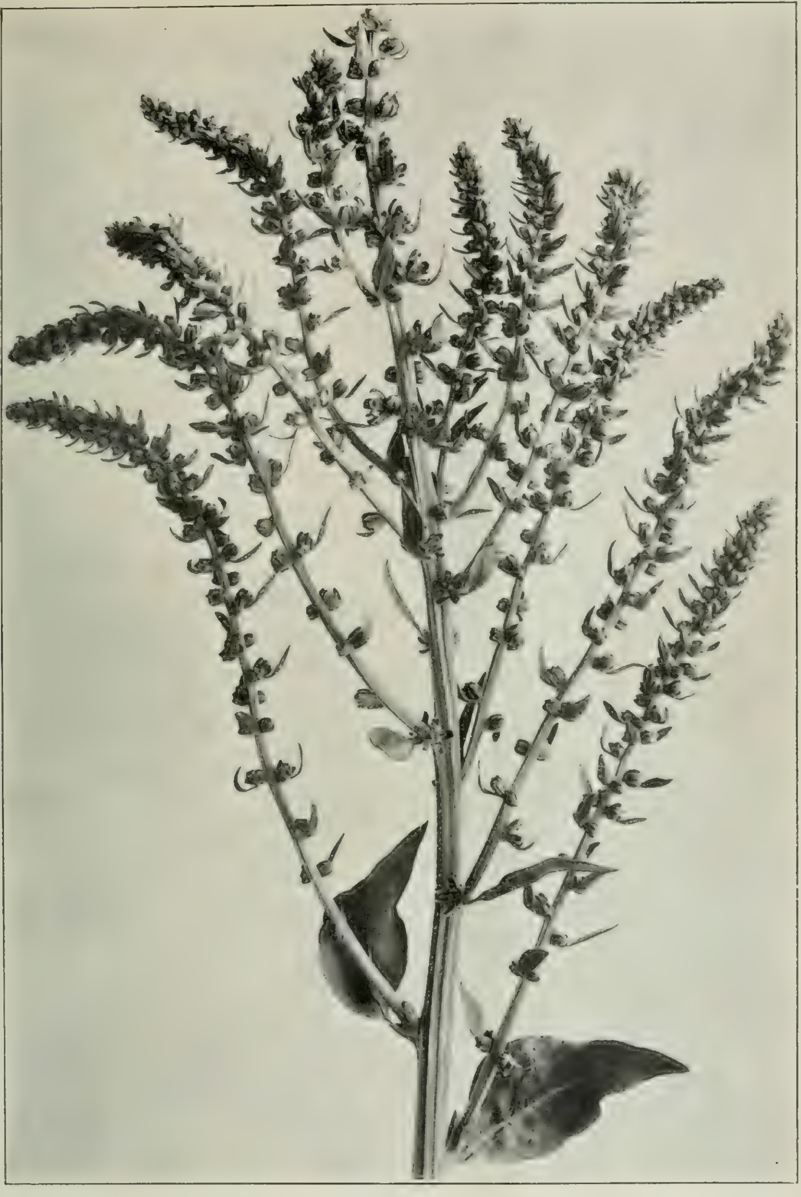
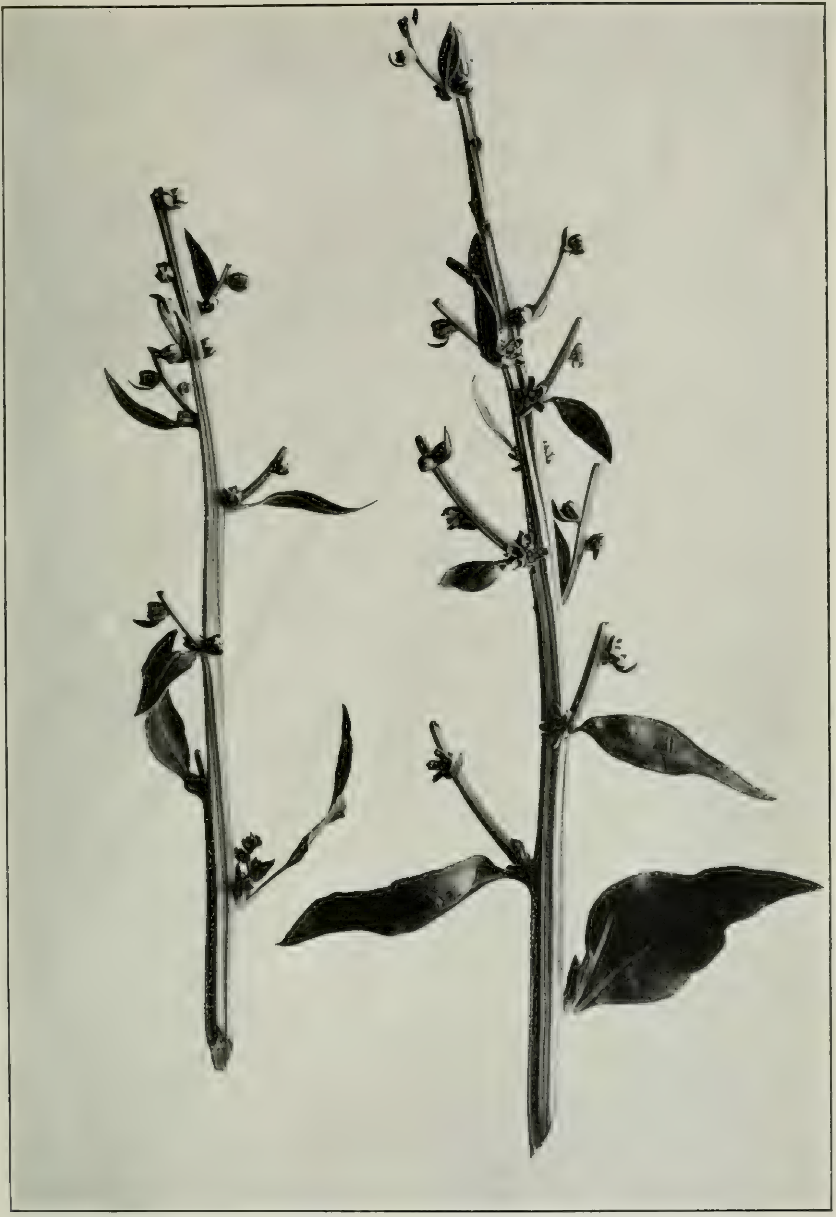


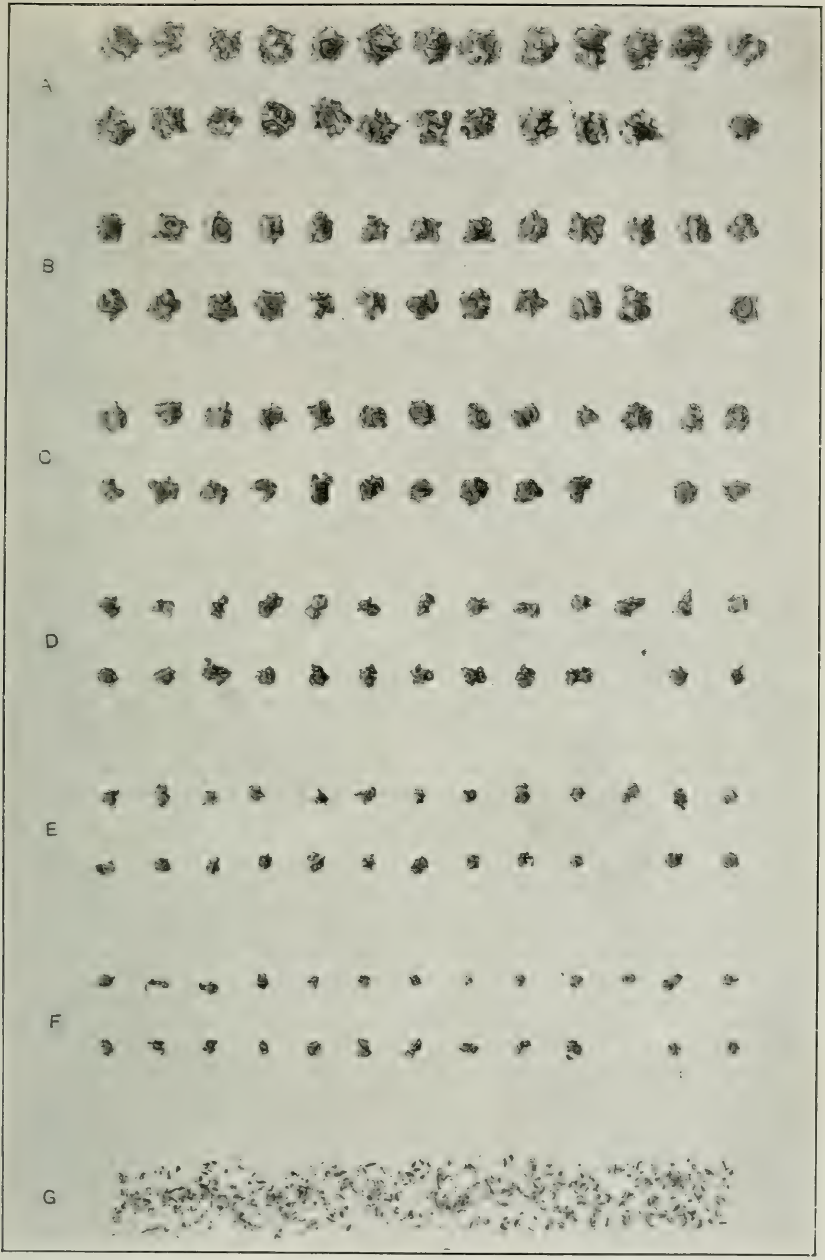
UPPER PART OF FLOWER STALK FROM BEET PLANT.

Natural size.



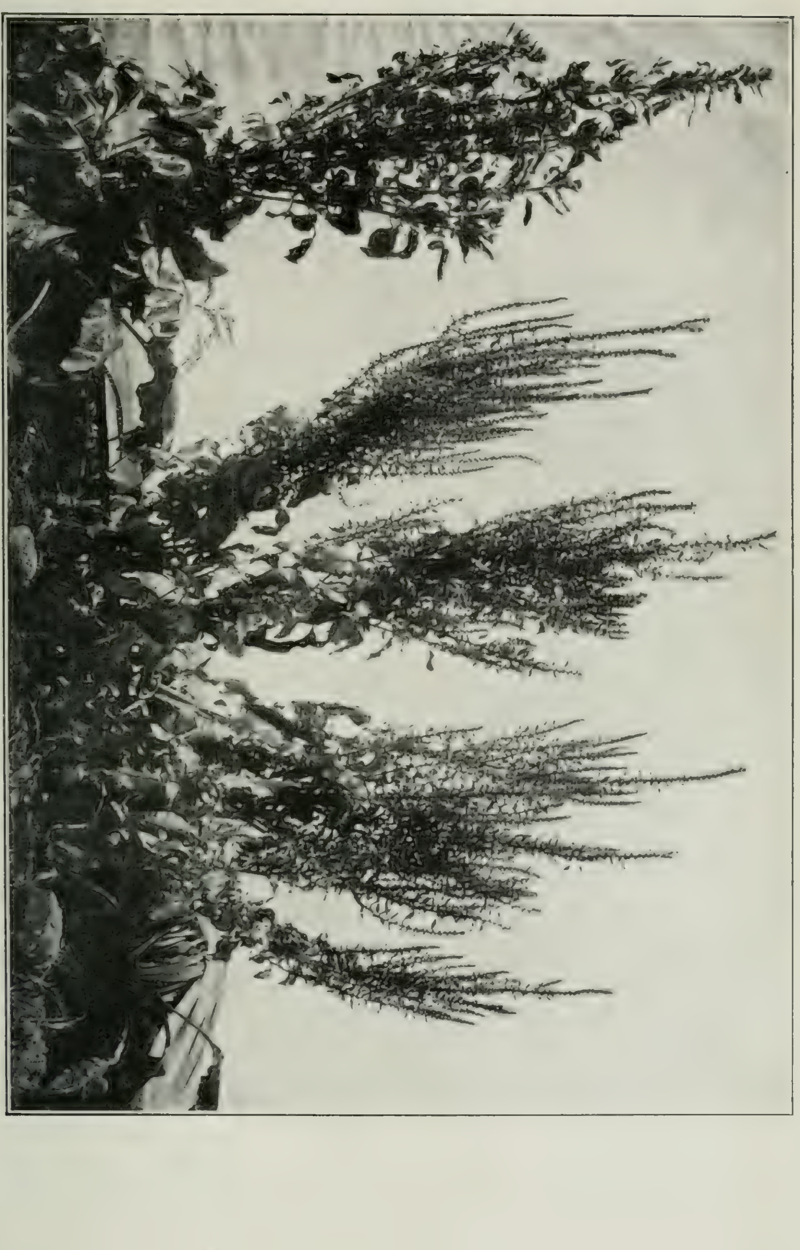
UPPER PARTS OF FLOWER STALKS, WITH ONLY SINGLE FLOWERS REMAINING.

Natural size.



A.—COMMERCIAL BEET SEEDS. B, C, D, E, F, G.—SIFTINGS.

Natural size.



TWO TYPES OF BEET-SEED STALKS.

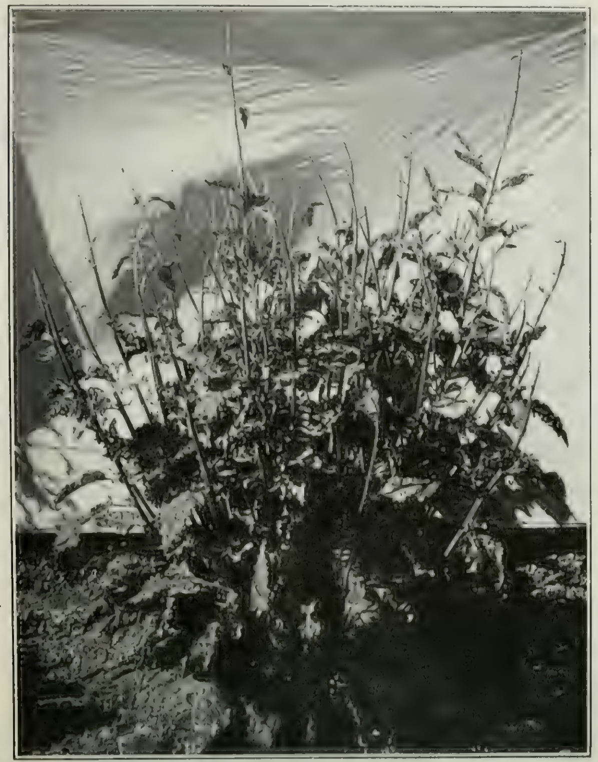


FIG. 1.—FLOWER STALKS WITH MULTIPLE FLOWERS REMOVED.

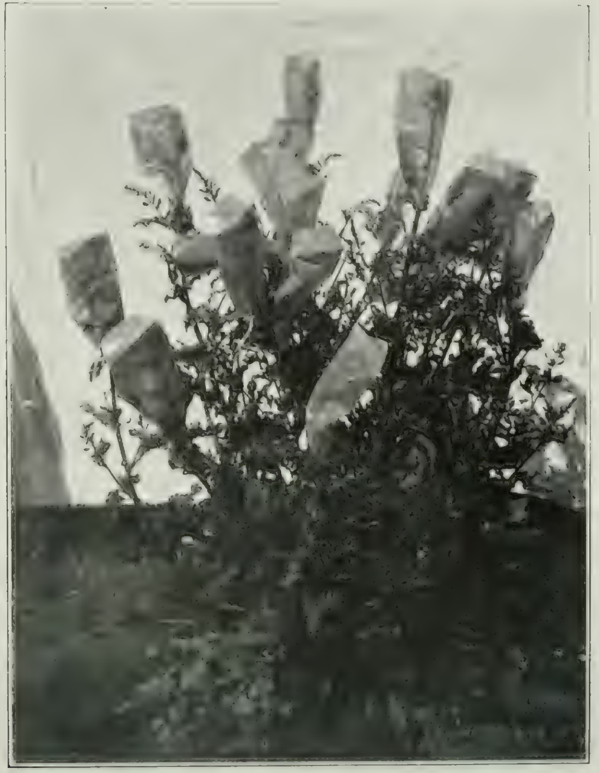


FIG. 2.—FLOWER STALKS POSSESSING ONLY SINGLE FLOWERS, COVERED WITH PAPER BAGS.

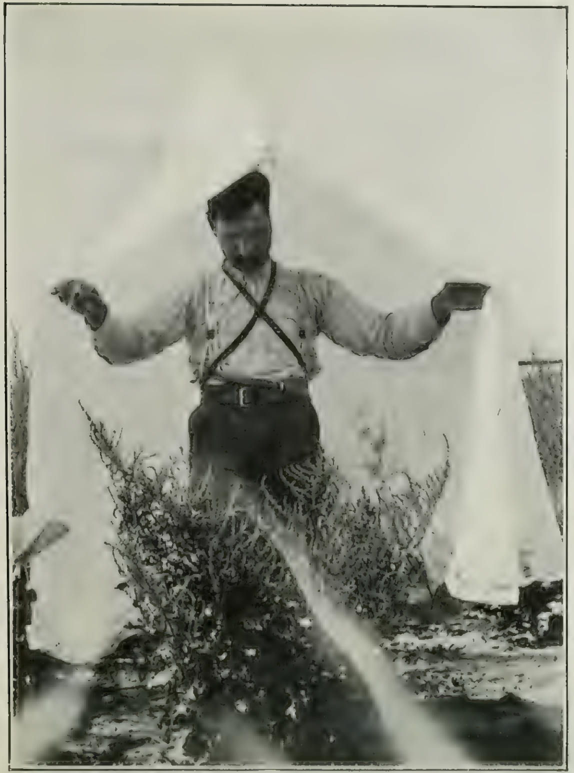


FIG. 1.—PLACING CLOTH TENT IN POSITION.

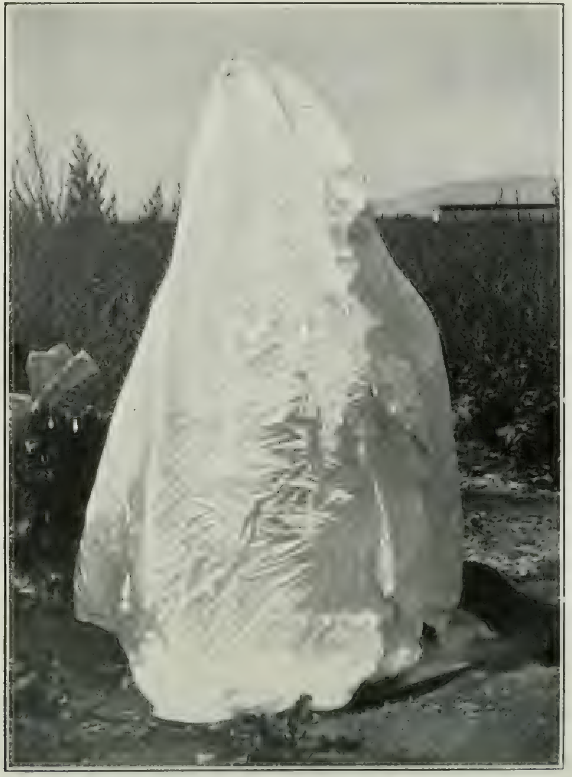


FIG. 2.—CLOTH TENT PROPERLY ADJUSTED.

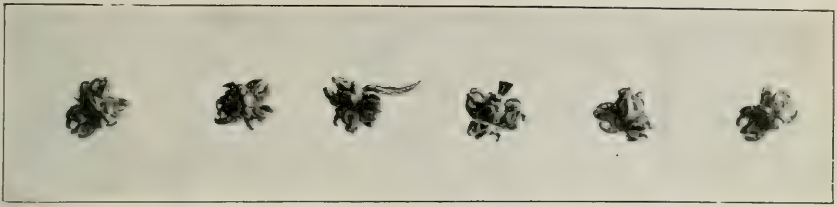


FIG. 1.—MULTIPLE-GERM BEET-SEED BALLS.

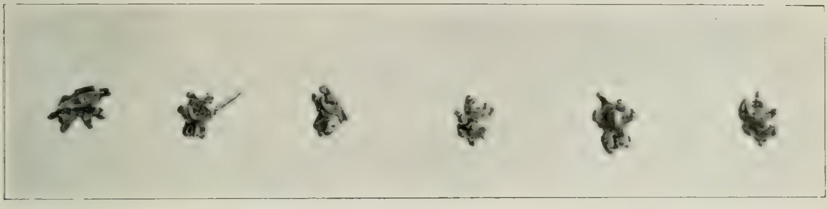


FIG. 2.—DOUBLE BEET-SEED BALLS.

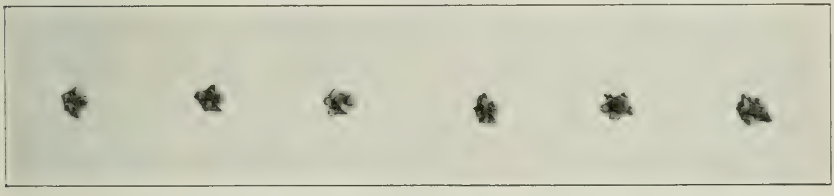


FIG. 3.—SINGLE-GERM BEET SEED, NATURALLY POLLINATED.

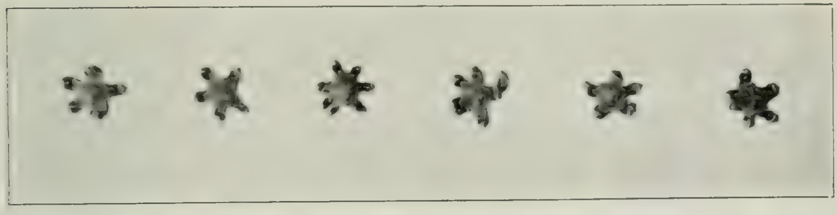


FIG. 4.—SINGLE-GERM BEET SEED, HAND POLLINATED.

VARIOUS FORMS OF SUGAR-BEET SEED.

Natural size

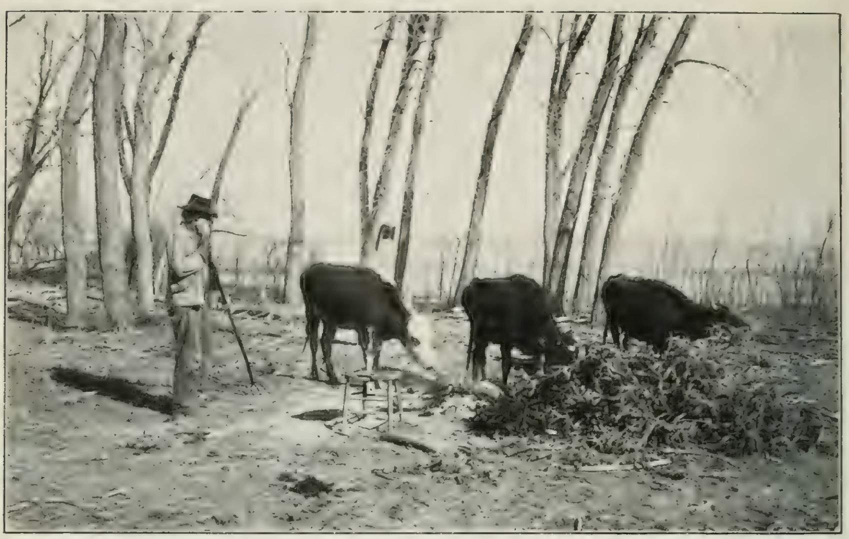


FIG. 1.—THE CANE CACTUS OF SOUTHEASTERN COLORADO, SINGED WITH BRUSH.

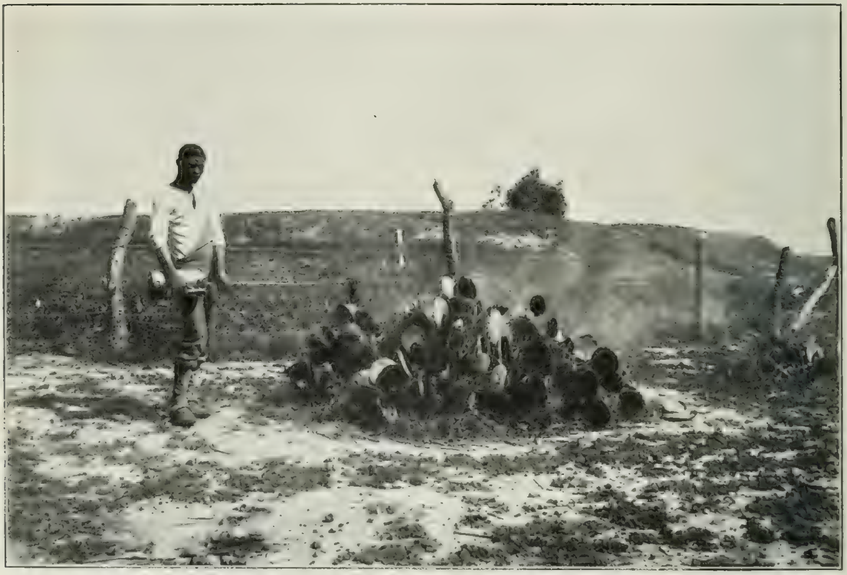


FIG. 2.—THE PRICKLY PEAR OF TEXAS, SINGED WITH A TORCH.

OLD AND NEW WAYS OF SINGEING CACTI.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 74.

B. T. GALLOWAY, *Chief of Bureau.*

THE PRICKLY PEAR AND OTHER CACTI AS FOOD FOR STOCK.

BY

DAVID GRIFFITHS,
Assistant Agrostologist in Charge of Range Investigations.

GRASS AND FORAGE PLANT INVESTIGATIONS.

Issued March 8, 1905.

239385
13.1.30

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., December 14, 1904.

Sir: I have the honor to transmit herewith, and to recommend for publication as Bulletin No. 74 of the series of this Bureau, the accompanying manuscript entitled "The Prickly Pear and Other Cacti as Food for Stock." This paper was prepared by Dr. David Griffiths, Assistant Agrostologist in Charge of Range Investigations, and has been submitted by the Agrostologist with a view to its publication.

The five half-tone plates are necessary to a complete understanding of the text of this bulletin.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

For several years past letters have been coming to this Office regarding the forage value of different species of cactus. Some two years ago a number of letters were received in which the writers claimed high feeding value for this class of plants when properly handled. The fact that much land which must be classed as desert is covered with a considerable growth of cactus plants, and the certainty that if these could be shown to have forage value the fact would render useful enormous stretches of lands which are now even worse than useless seemed to justify investigating the subject.

Our first efforts were to collect the experience of those who had used prickly pear and other cacti for feed. The amount of information secured in this manner was astonishingly large, and being on a subject which had hitherto received practically no attention from investigators in this country, much of it was of a nature to create some surprise. The information thus gleaned is here presented as a basis for further work, which is now under way. While the opinions of those who have had experience in feeding cactus are not always justified, they are nevertheless suggestive and are presented in the following pages because of the value of some of these suggestions. In view of the large amount of information collected by Doctor Griffiths, it is somewhat remarkable that investigators have not heretofore recognized the possibilities evidently existing in the cacti as forage plants. It is shown that this use of them is very old and is quite general over a large extent of territory in this country. In this connection it may be remarked that were it not for the spines on this class of plants they would probably have been exterminated long ago, and there is some doubt whether there would be any use for spineless forms in the future. It is practically certain that under no circumstances does the prickly pear possess as much forage value as some enthusiastic feeders claim for it, but the subject is certainly worthy of the investigations that have been undertaken. The principal lines of investigation now in progress are: Chemical composition of the most useful forms, methods of planting, yield, the frequency with which cacti may be harvested, varieties and their distribution, methods of preparation and feeding, and the value of these plants compared with other forage plants.

We have been able to find only very meager accounts of any previous investigations in this field. A little has been done in Australia and in India. The results of these investigations are not in accord with the experience of stockmen in this country. In reporting on feeding trials in India, the experimenter says, "The result of our extended and thorough trial proves conclusively that prickly pear has hardly any value as a cattle feed." In the experiments referred to, the cactus was roasted in order to remove the spines. The experience of American feeders indicates that the unfavorable results in these experiments may be due to the method of preparation of the material. They may also, of course, be due to differences in the species used, but the fact that practically all forms of cactus found in this country make very good famine feed would point to a different conclusion. The cattle on experiment in these investigations in India at no time consumed over 25 pounds of cactus per day, while numerous instances are known where cattle in this country have eaten 100 pounds or more per day.

It would seem that when fed with a limited amount of cotton-seed meal, properly prepared cactus is readily eaten in large quantities and that it has considerable feed value. Prickly pear has undoubtedly saved many herds in famine years and thus prevented the wiping out of the ranchers' capital—often the result of years of patient labor.

Other publications will be issued as the investigations now in progress are completed. These investigations are being conducted by Dr. David Griffiths, of this Office, under the direction of the Agrostologist. In this work we are cooperating extensively with the New Mexico Experiment Station and with a large number of stockmen in the Southwest.

W. J. Spillman,
Agrostologist in Charge.

Office of Grass and Forage Plant Investigations,
Washington, D. C., December 5, 1904.

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THE PRICKLY PEAR AND OTHER CACTI AS FOOD FOR STOCK.

INTRODUCTION.

In the arid and semiarid regions of the United States the rancher is periodically confronted with a condition of drought which endangers the well-being, if not the actual existence, of his flocks and herds. His pastures are usually taxed to their utmost capacity during average years, and when a season of famine occurs he suffers tremendous losses by death of animals. Under these conditions he is obliged to sell when neither his stock nor the market prices are favorable to his interests. Under such circumstances it is sometimes advisable to buy hay or grain, but the prices of these feeds where freight rates are high are often prohibitive. It is very seldom that a rancher can afford to feed hay at $10 per ton to stockers, even if it can be secured conveniently.

The case is much more aggravated when the haul to the feeding grounds is long, necessitating a considerable expenditure of money for hauling the same expensive feed. This latter expense may often be obviated by driving the stock to a region in close proximity to the feed; in other words, to the feeding ground. This common practice in the West is a very important factor in the stock business. Stockers are shipped from the southwest to the Pacific coast, Montana, and Canada to take advantage of feed in those localities when it is unobtainable in the southern breeding grounds. The practice, while common, if not universal, is expensive, because of the long distance to feed. Short pasture and the settling up of the intervening regions render driving impracticable, although formerly this could be more easily done. The large holder usually has a knowledge of the conditions which prevail in other sections of the country, and his superior experience gives him a decided advantage over the small rancher, who has less means and usually less knowledge of the conditions of the country at large at his command. The rancher of moderate means is therefore confronted, during years of famine, with the alternative of feeding expensive feed or selling at ruinous prices in order to save his stock from starvation.

It is to meet the requirements for an emergency ration for these seasons of short feed and to call attention to the varied uses of the cacti that this bulletin is published; and it is hoped that it will answer, in a preliminary way, many questions which are asked of the Department of Agriculture each year regarding cacti.

The various species of cactus which occur in the arid and semiarid portions of the country are well adapted to the purpose of feeding when properly prepared, and furnish a feed which, although low in nutritive value, is inexpensive and will tide the stock over a period of shortage.

This bulletin is based upon personal observations and the experience of ranchers, and was instigated by the numerous inquiries and pressing demands which have been apparent for the past few months. This publication is a preliminary one, giving a general exposition of the subject. It will be followed later by several technical treatises, which are now in process of preparation, dealing with carefully planned experiments upon the different phases of the subject. Here technicalities are avoided, and the aim in writing has been to include such information as has been secured by field observations and inquiry among ranchers, dairymen, teamsters, and others having experience in the premises. The paper is therefore intended to be popular, suggestive, and preliminary to more technical publications which are to follow.

HISTORY.

It is impossible to tell where or when the feeding of pear began in Texas, but it is certain that the practice was common several years before the civil war. There are people now living who can remember distinctly its use during the droughts of 1857 and 1859. From this time until long after the war there were very extensive freight transportations carried on between Brownsville, Indianola, San Antonio, Eagle Pass, etc. Teaming was especially heavy in this region during the civil war, when Brownsville and Matamoras, Mexico, became bustling, flourishing cities, built up by the teaming trade, which brought the products, especially cotton, of the Confederate States to this point for export—at times the only safe outlet for the products of the South. By far the greatest amount of freighting was done with oxen. At that time corn was not produced in any appreciable quantities, and any other grain was prohibitive in price. Upon their long hauls the cattle got no feed but that produced by the country through which they passed. This was meager in localities and often poor everywhere. It is said that the teamster considered himself fortunate when there was pear to be had, and there was plenty of it on many of the roads. The teamsters at this time scorched the pear by burning brush, and chopped or slashed it with ax, spade, or machete. This, together with such dry grass and browse as the region afforded, was all the feed that the cattle obtained.

It is quite probable that the Americans learned the use of prickly pear from the Spanish people, who appear to have learned its value and practiced feeding it long before it was employed for that purpose in this country.

GEOGRAPHICAL DISTRIBUTION OF ECONOMIC CACTI IN THE UNITED STATES.

Roughly speaking, we may designate the northern boundary of the cactus area in this country as follows: From the Texas–Louisiana line westward on the thirty-third degree of north latitude to the Texas–New Mexico border; thence, northward to the thirty-ninth degree of north latitude; thence, westward along this parallel. In describing the boundary in this manner it is to be understood that only a very small fraction of the area of the United States south of this line has pear or other cacti in sufficient quantity to be of economic importance in a state of nature. Indeed, the areas of economic cactus in this country are very circumscribed, although they are scattered over a considerable territory.

Outside of this area there are only one or two situations where the cacti are at all prominent, and they never grow large enough to be of any particular value. The same is true of much of the territory included in the general region designated above, but some of this territory is covered with growths of various species of these spiny plants that render it difficult for cattle to travel through them, and such growths are scattered here and there over the entire region.

The cactus region par excellence, and the only region where any great amount of feeding has been done in this country, may be described as that portion of Texas situated south of the thirtieth parallel of north latitude. In this region the species of prickly pear are sufficiently abundant and the grasses so scarce during portions of the year that the stock industry becomes almost dependent upon the pear for its existence. It is estimated by many ranchers that one-half less stock would have to be handled by them were it not for prickly pear.

In the general cactus region outside of southern Texas, cactus from an economic point of view occurs in limited areas only. Arizona, New Mexico, and southern California, while often spoken of as great cactus regions, have only comparatively small areas where any of the species grow in sufficient abundance to render them of any commercial importance in a condition of nature. These States have many botanical species of great interest, but in many cases the number of individuals is small, or, if numerous, they are too diminutive to be economically prepared for stock feeding.

But even so, there are many areas scattered all over these regions where some of the various species occur in great profusion, giving a reserve food supply which under intelligent use can be made immensely valuable, even if the plants will not respond readily when planted. The experience of a few ranchers in the vicinity of Magdalena, N. Mex., the Pinal Mountains and Colorado River Valley of Arizona, and in southeastern Colorado testifies to the value of the various species of cactus as emergency rations in the general region south of the thirty-ninth degree of north latitude and west of eastern Texas.

METHODS OF FEEDING.

In Australia, so far as the literature of the subject indicates, steaming is the principal method of utilizing the prickly pear, which has been introduced and widely disseminated in that country. In this country various methods have been developed independently in the several cactus regions, and apparently, at least, without knowledge of the practices in vogue in other sections. The greatest progress in this line, however, is exhibited in the vicinity of San Antonio, Tex.

SINGEING THE SPINES.

The most prevalent practice in southeastern Colorado consists in singeing the spines over a brush fire. (Pl. I, fig. 1.) This operation is practicable where there is considerable brush or wood conveniently situated, but it has many disadvantages. The plants are collected and hauled to some convenient place, where a fire is built. A brisk fire will remove the spines from one side of the joints almost instantly. It is then necessary to turn the plants over and burn them again on the other side. Some careful feeders often leave the plant on the fire until much of the outside has turned black from the heat, in order to insure the removal of the short as well as the long spines. Others exercise less care, and simply allow the flames to pass over the plant, burning off only the distal half or more of the long spines and leaving practically all of the short ones for the cattle to contend with. It often happens that the fuel used is greasewood (*Sarcobatus vermiculatus*) or shad scale (*Atriplex canescens*), the young shoots of which are of greater nutritive value than the pear itself. On the arroyos and washes dead cottonwood timber is used, while in many localities juniper furnishes the fuel.

This is the most primitive method of feeding and one which has been practiced in Texas since before the civil war, and is still very extensively employed not only in Texas but also in old Mexico, where singeing the thorns with brush is about the only method employed in feeding prickly pear and other species of cacti.

SINGEING WITH A TORCH.

The use of a gasoline torch for removing the spines of the prickly pear (and it is applicable to other species of cacti) originated in Texas. (Pl. I, fig. 2.) This is a common practice in vogue upon the range, and is to be recommended as economical in both the utility of the feed and the labor of preparing it. The process consists in passing a hot-blast flame over the surface of the plant, which can be very quickly done at small expense. The spines themselves are dry and inflammable. In many species one-half or two-thirds of them will burn off by touching a match to them at the lower part of the trunk. The ease with which they are removed depends upon the condition of the atmosphere, the age of the joints, and the number of the spines. A large number of spines is very often an advantage when singeing is to be practiced, because the spines burn better when they are abundant. The instrument used for this purpose is a modified plumber's torch. Any other convenient torch which gives a good flame can be employed, the efficiency depending upon the lightness of the machine and the ease with which the innermost parts of the cactus plants can be reached by the flame.

In southern Texas two excellent torches, described elsewhere, are commonly used in singeing the prickly pear. In Arizona one or two ranchers consulted have used an ordinary kerosene torch with moderate success in handling the tree cacti of that region. With the use of these machines there is no labor involved in the feeding, except that of removing the spines by the passage of the blast flame over the surface of the joints. The cattle follow the operator closely, and graze all the joints which have been singed.

STEAMING.

So far as known, Mr. J. M. John, of Hoehne, Colo., is the only rancher who has practiced steaming cactus for cattle in this country. Mr. John discovered by accident and without any knowledge of Australian practices that the spines became innocuous when moistened for some time. He happened to use the plants in the construction of a dam, which soon washed out. Upon repairing the dam it was discovered that the spines of those plants which had been kept wet were perfectly harmless. This suggested that hot water or steam would accomplish the purpose in a much shorter time. Acting upon this suggestion he fitted up a tank and boiler, which happened to be on hand, for the purpose of steaming the cactus. The tank employed was an open one holding two loads, or, approximately, 6,000 pounds of cactus. In order to prevent the loss of heat as much as possible, corn chop, which was to be fed with the cactus, was poured upon the top of the loaded vat. This mixture was steamed for about ten hours, allowed to stand one night, and fed in the morning, with good results during one or two winters. It should be stated that all of the liquid was lost. This was a pure experiment, adapted to local conditions and material convenient for the operations. The form of tank, the length of time, and the consequent expense of keeping up steam, could be greatly improved upon.

CHOPPING BY MACHINERY.

In southern Texas there have been some rapid advances made during the last twenty years in the matter of pear-handling machinery. By use of the machines now in vogue pear and other cacti may be chopped into such small pieces that the spines are rendered innocuous by the abrasion. The two machines manufactured for this purpose and described later are both set so as to cut the pear into 1-inch to 1½-inch pieces. Owing to the succulent nature, the whole thing is practically macerated in the operation. It is the practice to set these machines up in the pastures convenient to pear and water. The pear is cut down, hauled to the machines in wagons or carts, chopped, reloaded, and hauled out again to be fed in troughs constructed for that purpose.

A further discussion of this topic will necessarily occur in connection with a description of the machines and their operation.

OTHER CHOPPING DEVICES.

Many feeders in Texas hire cheap labor to chop the prickly pear with machetes or spades. A small quantity of the pear is placed in a trough or a pile is built upon the ground. A machete or spade is then employed to slash it into small pieces, when it can be more readily eaten by the cattle. This is rather a poor way of feeding, for the spines are only imperfectly gotten rid of, and the cattle consequently get their mouths so full of them that after a time they are unable to eat at all. The practice does get rid of some of the spines, however, and stock are able to eat the pear much better when prepared in this way than in the natural state.

REMOVAL OF THE EDGE OF THE JOINTS.

All pastors (herders) carry machetes as a part of their equipment in all prickly-pear regions of Texas and Old Mexico. With this most useful Mexican instrument they very dextrously lop off the edge of the pear joint for the purpose of giving the sheep a chance to get into the thickets or bunches of pear to better advantage. As a usual thing the greatest number of spines occur on the edges of the joints, the more effectually protecting them. The pastors simply cut off an inch or two of this spiny portion and the animals are then able to nibble at the cut surface without serious injury. This practice has probably done more toward the creation of impenetrable thickets than any other, for a large number of the pieces which are cut off strike root and grow.

HANDLING THE PLANTS.

The species of cactus which is fed in southeastern Colorado is one of the so-called tree cacti. The spines are very numerous upon this species, rendering it difficult to handle, so an ordinary fork is used to collect and handle it over the fire. Some feeders employ an ax in cutting the tree down, but the majority of them use a fork for that purpose also. A comparatively small pressure of the fork against a large limb is sufficient either to break it off or cause it to split at the crotch, when it can be loaded directly on the wagon which is driven along for this purpose. The limbs break off very readily when they are frosty. If collected in cool, crisp mornings, therefore, chopping is not necessary, for a simple pressure of the fork will break off a large limb. An average load upon a hay frame will weigh 2,000 to 3,000 pounds. This the collector can gather and throw upon the wagon with no particular attention to the arrangement of the plants, as with a load of hay. The practice in vogue requires a great deal of handling. The plants are first loaded on the wagon, thrown off in heaps, forked over at least twice in the singeing, and then thrown out to the cattle to feed upon. This makes not less than four handlings. The feed is comparatively easy to handle, however, a large branch, such as is usually obtained, weighing as much or more than an average forkful of hay.

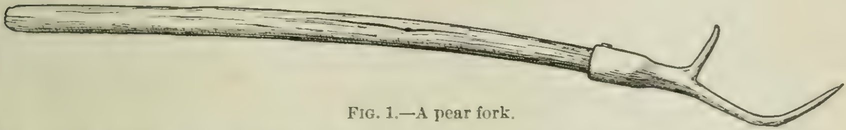

FIG. 1.—A pear fork.

In southern Texas the handling does not differ very materially from that described for southern Colorado, except in unimportant details. Here, on account of the peculiar influence of the Mexican labor employed, the methods are often very primitive. Instead of a fork, a sharpened or forked stick is often used in gathering and hauling the pear of this region. In feeding to the pear choppers a stick is invariably employed, on account of the danger to the knives of the machine when an iron fork is used.

In some cases a specially constructed fork (fig. 1) is used by the freighters. This instrument has a handle much like an ordinary pitchfork; the tine, however, is single, short, stout, and sharply curved, with a stout buttress or projecting arm at the base to prevent the soft joints through which the instrument is thrust from sliding upon the handle when raised above the operator in the act of pitching upon the wagon. None of these was seen upon the ranges, but such forks were commonly used by the wood choppers and freighters.

The vast majority of the Mexicans used a forked stick, and this is the only method of handling which was observed in old Mexico, where pear feeding is very extensively practiced.

PEAR MACHINERY.

So far as the writer is aware, all pear machines that have been invented—and there are four of them—have emanated from the country tributary to San Antonio, Tex. At present there are four machines in common use, two choppers and two torches, as described below.

ORIGIN OF PEAR MACHINERY.

Dr. W. S. Carruthers, a retired army surgeon, is said to have originated the idea of pear-cutting machinery. Doctor Carruthers submitted a sketch with notes to a foundryman at San Antonio, Tex., who put the idea into mechanical execution about 1886 or 1887.

The first machine was constructed of wood. It consisted essentially of a vertically mounted revolving wheel, with an iron band shrunken upon it in much the same way as the tire of a wagon wheel. Knives for cutting the pear were fastened to the surface of this wheel. It was not essentially different in principle from the machines of more modern construction. Although many mechanical improvements on the original machine have been made, it is admitted that the honor of the invention belongs to Doctor Carruthers, who not only designed the original, but was the first to operate a pear-cutting machine.

Mr. T. R. Keck, of Cotoula, Tex., who was associated with Doctor Carruthers during his experimentation with his first machine, reports that the first machine used was made by himself out of boards and two old hay knives. This machine was used one winter on a very small scale as an experiment in testing the efficiency of pear and cotton-seed meal for fattening cattle. The following winter about 5,000 head of cattle were fed upon cotton-seed meal and machine-cut pear. Mr. Keck reports that the first homemade machine was used in 1885, as nearly as he can remember.

Since the invention of the pear choppers, some feeders have used some of the standard fodder cutters with moderate success. It is difficult to feed pear to these machines, however, for they are not run at a high enough rate of speed to get rid of the spines. They are not suitable for handling pear.

PEAR CUTTERS.

The machine shown in Plate II, figure 2, consists essentially of a solid cast-iron wheel, 4 feet in diameter, with two knives arranged at a narrow angle with the radius on one of its faces. Behind each knife, hollowed out of the face of the solid casting, there is a pocket extending the length of the radius. The front face of this wheel is plain, save for these pockets, which receive the chopped pear and carry it out of the machine. These are 1¼ inches deep, 22 inches long, and 9 inches wide. The back of the wheel is made irregular by the projection of the knife pockets, radial thickenings, and a perimeter 2 inches wide, for strengthening the casting.

The knives are bolted on to the face of the wheel over the pockets, and are one-half inch in thickness, with a bevel toward the wheel. In revolving, the knives pass a shear plate which is adjustable and bolted into the frame.

The wheel is supported vertically on a horizontal shaft running in boxes supported on a wooden frame. The wheel is operated by a pair of gears with a ratio of 5½ to 1, the shaft of which is squared to receive the knuckle of the horsepower ground rod. The main shaft also has sprockets for the operation of the carrier chain. To it also may be attached a pulley for the adaptation of steam power. When the machine is set up, a short chute is bolted at an acute angle with the face of the vertical wheel, in such a position that it terminates in the same horizontal plane as the axis of the wheel. The pear is forked into the chute, fed against the face of the wheel with its revolving knives, and is cut and mashed into small pieces. The chopped material is carried down in the pockets and dropped into a carrier, operated upon the same principle as the common straw stacker, which carries the chop off into whatever receptacle is provided for it. This is usually the ordinary wagon box, for the chop is hauled directly from the machine to the feeding ground.

The machine as operated by Mr. J. C. Glass, of Eagle Pass, Tex., has a few labor-saving devices attached to the regular construction as shipped from the factory. Upon the cutting side and opposite the horsepower a large platform about 3½ feet high is constructed to reach up to and partially surround the wheel. This is large enough to hold one day's feed of uncut pear, which is thrown on to it from wagons. From this platform the pear is fed into the chute, which is situated just above it. Under the elevated carrier is constructed a triangular box of about the same capacity as a double wagon box. On the lower end of this is a trap gate which can be sprung so as to allow the chop to slide into the wagon with no handling. The cost of the machine, together with the additional construction, is about $125.

The machine has never been worked by Mr. Glass to its full capacity, but an estimate can be made of its efficiency from the operations during the drought of 1902. At that time an average of seven or eight men was employed, and they cut pear for 1,500 head of cattle. Ten men could be employed to better advantage, and it is estimated that this number could, with pear conveniently at hand, cut a full ration for 2,000 head of cattle. This means that the machine would be operated ten hours a day, and that four horses would be necessary to furnish the power. The machine is calculated to be run by two horses, but four operate it to much better advantage, especially if heavy, old pear is used and a large amount of material is to be cut.

It was the practice here to run the machine only about six hours a day, the entire crew being employed in cutting and feeding and in gathering pear from the field. The cutting occupied the forenoon and a part of the afternoon, while the gathering required only a portion of the afternoon of each day. By employing men enough both to run the machine and gather the pear, thereby operating the machine ten hours a day, there is little doubt that ten men could feed 2,000 cattle a full ration. Seven men constitute the operating crew, and three can supply them with pear if the haul is not too great.

The machine shown in Plate III, figures 1 and 2, is constructed throughout of iron. It has a 36-inch revolving wheel, in which three adjustable knives are set at a narrow angle with the radius of the wheel. Behind each knife are set cast-iron pieces, which, bolted upon the wheel, make a box 2½ inches deep opening upon the periphery. The entire wheel is cased in, except the delivery opening, through which the chopped pear is thrown out of the machine. The knives cut against a shear plate, essentially as in the machine first mentioned, and a feed hopper or chute is built of boards, as described for that cutter. No carrier is used with this machine, for the centrifugal force of the revolving wheel throws the cut material 30 or 40 feet. A back stop 10 feet high is usually built to stop the chop, where it can be shoveled up handily.

If the cutter is run with an engine and fed steadily, the centrifugal force delivers the chop into a wagon, but with a horse power and unsteady feeding the motion is not uniform enough for this, and the chop must be shoveled into the wagon. The wheel makes about 225 revolutions a minute when operated by four strong animals. It is claimed that it will chop 20,000 pounds of pear an hour.

Mr. T. A. Coleman, of Encinal, Tex., operates this cutter with an engine, and all of his hauling is done in the common Mexican ox cart. A cover is constructed of lumber to fit each cart. This is put in place and fastened down, when the cart is backed up to the machine in such a position that the chop is delivered into the rear end, which is left open, by the centrifugal force of the revolving wheel. In this way the carts are not only thoroughly but uniformly filled.

While the pear is passing through the machine the spines become thoroughly broken up, and, being lighter than the pulpy material, are largely winnowed out when the chop passes out of the machine. Ranchers report that this is very noticeable when the machine is in operation, the stream of broken spines and lighter material being quite effectually separated a few feet from the machine.

With this, as with the other machine, it is necessary to build a platform and a feed chute from which the pear is fed with sticks, as previously described. The chute is in the form of a flat trough, set at an angle of 45 degrees from the face of the wheel, its base being coincident with the horizontal diameter. The pear to be chopped is in this way carried into the machine by its own weight for the most part, but, owing to its straggling method of growth, its passage into the machine must be facilitated by the use of crude forks. The machine differs from that shown in Plate II, figure 2, in being constructed of iron throughout, in being smaller and more compact, in having the boxes behind the knives removable, and in utilizing the centrifugal force of the wheel in discharging the chop.

Both machines are reported to be very efficient. There is but little about them to wear out, and they are reported to last indefinitely.

PEAR BURNERS.

Pear burners were first manufactured in 1898. As now used they are essentially a modification of the plumber's torch.

The two pear burners upon the market are very similar in construction and are both efficient machines, according to the best evidence that it has been possible to obtain. They consist essentially of a strong, well-riveted, metal tank, which in actual use is supported upon the shoulders of the operator by a strap; a long delivery pipe, and a burner for generating and consuming gas from gasoline. The two machines differ only in minor mechanical contrivances and in the form of the burner. It has been found by experience that it is absolutely essential that the tank be strongly built in order to prevent accident. Several of the first burners used were too light in construction and caused serious accidents. It is said that one or two men were killed by the explosion of the tanks and the burning of the gasoline.

The distinguishing features of one of the pear burners on the market are the turning joints of the delivery pipe and the simple coiled-pipe burner, which is covered with a sheet-iron cylinder to prevent escape of heat, to give direction to the flame, and to protect the burner in windy weather.

The other style of burner differs from the one just described mainly in the burner, which is somewhat more complicated. The generated gas in this machine passes through a chamber filled with a bundle of fine brass wires before being ignited. It also has some safety arrangements for insuring the heating of the oil and consequent generation of gas, which are claimed to have merit.

Both machines require gasoline for their operation, and are handled to best advantage with a good quality of oil and in weather free from wind.

Practically no labor is necessary with the burners other than that of passing the blast flame from the torch over the surface of the joints momentarily. Indeed, it is not usually necessary to do this with over two-thirds of the plant, for there is commonly enough dead herbage at the base, and growing up through the pear plants, to assist in burning off at least one-half of the spines. Besides, the spines are commonly less numerous upon the old stems, and cattle experience but little difficulty in eating the remainder after the outer two to four joints have been freed of them. The process of singeing the joints with one of these machines is therefore not a laborious or expensive one. Indeed it is by far the cheapest method yet devised for utilizing the prickly pear. It has, however, one or two disadvantages which are discussed later.

Cattle brought up in pear pastures do not have to be taught to eat pear. They take to the feed very naturally. After a day or two of feeding the sound of the pear burners, or the sight of smoke when pear is burned with brush, brings the whole herd to the spot immediately, and they follow the operator closely all day long, grazing the pear to the ground—old woody stems and all—if the supply that the operator can furnish is short.

PEAR FOR MILK PRODUCTION.

It is universally recognized throughout the pear region of southwestern Texas that the plant has a decided tendency to increase the flow of milk. In spite of the fact that the average ranch feeder claims that pear is of little or no value in the summer, there are hundreds of people who feed more or less definite quantities of this plant from one year's end to another. It is always used as a supplementary ration. Pear alone has not been fed to a great extent, for it is recognized that it is properly a supplementary ration to a more concentrated feed. Mr. John Bowles, near Eagle Pass, has fed pear, with hay and bran, to a milch cow for the past three years and would not think of discontinuing the practice. Some dairymen in the small towns where pear is accessible feed it regularly, and nearly all of the Mexican families who keep a cow in town depend upon this as their mainstay.

One example of very successful feeding, where somewhat definite data were obtainable, came under the observation of the writer and might be cited here. Mr. Albert Ingle, of Eagle Pass, Tex., keeps one Jersey cow to supply milk and butter for family use. The cow has the run of the commons about town, but the pasturage is very short the greater part oi the time. In addition to what she can pick up in this way she is fed 3 quarts of bran, 1 quart of cotton-seed meal, and all the singed and chopped pear she will eat. Mr. Ingle was feeding when his place was visited. The quantity chopped that morning, he stated, was an average one, and weighed 35 pounds, which amount was fed twice each day. The cow at the time was raising a calf and furnishing milk for the family, and was in good milking condition. This shows that the amount of pear fed was large. The ration each day was 6 quarts of bran, 2 quarts of cotton-seed meal, 70 pounds of chopped pear, and what the animal was able to pick up on very short range. This ration is kept up during the year, except when the mesquite beans are abundant, when no pear is fed.

The experience of Mr. Alexander Sinclair appears to be exhaustive and intelligent. He does not claim for pear any great feeding value, but he uses it entirely, he says, for the succulence. So far as feed is concerned, even roughage of some other kind could be fed cheaper, but as a succulence for milk production there is but little that can be secured during the winter. Attempting, as he does, to maintain an equal milk and butter production during the entire year, green feed is essential for winter use. This is furnished by the prickly pear, which is fed during that portion of the year when there is no green feed. During a portion of the summer, succulence is secured from the native grasses. When these dry up green sorghum is fed, and during the remainder of the year prickly pear. In spite of the fact that the range feeders taboo the pear after it begins to grow, Mr. Sinclair has fed it well into May with good results.

The ration of a cow during the winter is about as follows: Cotton-seed meal, 3 pounds; brewers' grains, 9 pounds; pear, 100 pounds.

Besides the above, the cows have the run of brushy pastures and are able to pick up much in the form of dry grass and browse. The quantity of pear fed is only an estimate, but is thought to be very close to the amount which an average cow gets. Even with this apparently large amount of pear the animals never get all they want of it. With this feeding the milk production is greater in the winter than in the summer when the cattle are on good grass. This, however, is not considered to be due to any peculiar advantage of the pear over the native grass, but rather to the unfavorable temperature and the annoyance of insect pests in summer.

Originally it was the custom to chop the pear with a pear cutter, but during the past winter it was hauled a distance of six miles, unloaded in long rows in the feeding lots, and singed with a pear burner.

Mr. Thomas Duggar, of Hoehne, Colo., has fed the common tree cactus of that region to milk cows with good success. The information secured from Mr. Duggar, while not so definite as that which one is able to obtain from the dairymen around San Antonio, Tex., where the feeding is better established and not so much of an experiment, nevertheless indicates that the cane cactus of this region is probably as good feed for milk production as prickly pear. Cactus, singed with brush, has been fed with a good quality of hay for two or three winters with what is considered good results. Doubtless some concentrated feed stuff, such as cotton-seed products, or corn chop, would add very materially to the quality of the ration for milk production.

SOME DAIRY RATIONS INCLUDING PEAR.

The practice of feeding dairy cows upon a partial ration of pear is very common—indeed, general—in the entire region of the lower Rio Grande, and as far north as San Antonio, Tex. The necessity for feeding this plant depends upon the condition of the seasons. When the winter rains are abundant and green feed is plentiful no pear to speak of is fed; but during a dry winter it is resorted to as the most economical method of supplying the succulence so essential to the maintenance of a good flow of milk. The amount fed depends largely upon the quantity of pear available and the labor at hand for handling it. In some cases which have come under the writer's direct observation the pear has been hauled six miles to feed to dairy cattle, and it is as much prized by many dairymen as any other part of their feedstuffs.

Mr. J. W. Statcher feeds 100 dairy cows regularly for three or four months during the winter. The feeding begins when the leaves fall off the brush in the autumn, and continues until they appear again in the spring. The ration for a cow is about as follows: Cotton-seed meal, 2 pounds; cotton-seed hulls, 8 pounds; bran of wheat or rice, 1 gallon; singed pear, 40 pounds; the run of brush pasture.

Mr. J. G. Hagenson's practice does not differ materially from that of Mr. Statcher. Having no pear, however, he buys it at 25 cents per load, a load consisting of about 2,000 pounds. His cattle get a ration approximately as follows: Bran, 9 pounds; cotton-seed hulls, 10 pounds; singed pear, 30 to 40 pounds; the run of dry-brush pasture.

In order to secure a better idea of the practices in vogue in feeding pear in the vicinity of San Antonio than time for personal inquiry would warrant, a circular letter was addressed to several dairymen. The following questions and answers in connection with the above discussion give a good idea of the practices which obtain and the estimate placed upon the prickly pear of the region as a succulence for milk production. Answers to the questions proposed were furnished by several dairymen. The following are considered typical, and are reproduced here practically in full:

(1) Do you feed prickly pear to your dairy herd? How many years has this practice been followed?

Answers.—(*a*) During the winter months only. (*b*) I do in winter; five years. (*c*) Yes; for fourteen years. (*d*) Yes; have fed off and on for a number of years. (*e*) Yes; during the winter time; for about twelve years. (*f*) I have fed prickly pear to my dairy cows for nine years.

(2) How long did you feed during the past winter?

Answers.—(*a*) About fourteen weeks. (*b*) All winter. (*c*) All winter. (*d*) Did not feed pear last winter, because other feeds were very cheap. (*e*) None at all. (*f*) Did not feed during the past winter, on account of having moved to a place where it was inconvenient to get it.

(3) How do you prepare prickly pear for feeding?

Answers.—(*a*) Make brush fire and burn thorns off. (*b*) I use a pear burner. (*c*) Singe the thorns off and cut it up. (*d*) I run the pear through a pear cutter and mix with cotton-seed meal and hulls. (*e*) Burn the thorns off; then chop in small pieces. (*f*) I first burn off the thorns with a dry brush fire, and then cut into small pieces with a large carving knife.

(4) How much pear do you feed a cow each day? If you do not know the exact number of pounds, estimate it as closely as possible. How many loads per day do you feed to how many cows?

Answers.—(*a*) I feed about two-thirds of a common water bucket full to each cow in the morning. (*b*) I give the cows as much as they can eat once a day. (*c*) About 10 or 15 pounds per cow. (*d*) I feed 1½ bushels to a cow each day. (*e*) One load of about 3,000 pounds lasts 16 cows about three days. (*f*) I give each cow about 6 gallons of pear cut up into pieces about 2½ inches square.

(5) What other feeds do you give the cows with pear? How much of each kind of feed per cow?

Answers.—(*a*) I feed cotton-seed meal and bran. (*b*) Bran and cotton-seed meal. (*c*) One quart of cotton-seed meal, 1 peck of cotton-seed hulls, and all the cane they want. (*d*) One quart of cotton seed, 1 quart of cotton-seed meal, and 20 pounds of hulls per day. (*e*) One and one-half quarts of cotton-seed meal, 8 quarts of wheat bran, 20 pounds of cotton-seed hulls. (*f*) I give my cows 10 pounds per day of a mixture of cotton seed and wheat bran, in addition to the 6 gallons of prickly pear.

(6) Do your cows have the run of any pasture while you feed pear?

Answers.—(*a*) Yes. (*b*) Yes. (*c*) Yes. (*d*) No. (*e*) Very little. (*f*) Yes.

(7) Do you consider that pear influences the flavor, odor, or quality of the milk in any way?

Answers.—(*a*) It does if fed more than two-thirds of a common water bucket full to each cow in the morning, or in any other way. Feeding at night affects the odor of the milk slightly and gives butter a pale color. (*b*) It increases the quantity of milk 40 per cent. (*c*) It does not affect the flavor or color, but it may reduce the weight or richness of it. It increases the quantity. (*d*) No; I do not think it influences the flavor, odor, or quality of the milk at all when fed as I have mentioned. (*e*) When too much pear is fed, and not enough solid feed, the milk has a peculiar odor, is very poor in quality, and blue in color. (*f*) Prickly pear does not injure the flavor of the milk. It increases the flow. Cattle are very fond of it.

(8) Do you have pear in your pastures, or do you buy it? If you buy, how much do you pay per load?

Answers.—(*a*) I have it in my pastures. (*b*) I have pear in my pastures. (*c*) Yes. (*d*) I buy it at 25 cents per load and haul it myself. (*e*) I buy my pear. It costs me 25 cents per load of 3,000 pounds. I haul it myself. (*f*) I have pear in my pastures.

(9) What is your estimate of the value of pear for milk production?

Answers.—(*a*) I consider pear very valuable as a feed, and it is a good milk producer. It is very healthful to be fed with cotton-seed meal, etc. (*b*) [No answer.] (*c*) It is far ahead of any kind of hay or forage, and mixed with meal or bran nothing can beat it. (*d*) Is a good milk and butter producer. (*e*) A very good feed when you have no roughage. (*f*) It does not pay to buy pear unless hay is scarce and dear. When sorghum hay is only $7.50 per ton, as it is now, hay is cheaper than pear at 25 cents per load when you have to haul and burn it.

(10) After a crop of pear has been cut, how many years will it take for another crop to grow on the same land?

Answers.—(*a*) About two; but this will depend a good deal on the season. Pear burners are discarded by some, for the reason that they destroy the plant. (*b*) The pear begins to grow the following year. (*c*) Three years. (*d*) It takes from three to five years to make good-sized pear. (*e*) I do not know, but think about two years. (*f*) About two years.

It is very difficult to formulate a definite opinion regarding the effect of pear upon the quality of milk. There appears, however, to be a very well-established opinion that it produces blue milk if not fed with concentrated feeds. There seems to be a great diversity of opinion regarding the flavor of milk from pear-fed cows. Many maintain stoutly that it produces a slightly bitter taste, which is less noticeable when a good ration of corn or cotton-seed meal is added, while others defy tests that will detect in any way pear milk from any other except by its poorer quality in cases where the amount of pear fed is large and the entire ration is of low nutritive value. Personally the writer has been unable to verify any of these opinions.

PEAR FOR FATTENING AND MAINTAINING CATTLE.

Since the early days when teaming was much more extensively practiced than at the present time, the bulk of the pear feeding in southern Texas has been done either to maintain stock or to prepare them for the market. While feeding cactus to dairy cows and work oxen is common all over the pear region, the amount fed for these purposes is insignificant compared with that used for maintenance and fattening. By far the greatest amount is fed as an emergency ration, to keep cattle alive during a severe and prolonged drought. For this purpose its value can not well be overestimated, for, as has been aptly said by many ranchers consulted during the past year, pear often means the difference between live and dead cattle. A drought of from four to seven months, as sometimes occurs, in a country which has no sod to speak of and where a large portion of the grazing is furnished by annual plants of short duration, is fraught with serious consequences to the stock industry. A rancher works faithfully a fourth of his lifetime to get his herd up to the desired standard of numbers and quality when a drought strikes him and he is obliged to sacrifice possibly his entire herd. He naturally waits for the weather to change from week to week, until his animals get into such a condition that he dares not move them, and they are then in too low a condition physically to be disposed of at anything like what they are worth, to say nothing about what they have cost him. In such a plight he loses everything, or sells out at a figure which practically means an entire loss, when it is almost certain that if he could keep his animals alive for a month or two there would be feed again and he would be out of danger. It is this uncertainty of the seasons which has often made the grazing of native pasture both hazardous and expensive in the Southwest. The rancher with small means is often caught with his cattle so poor that he can not think of moving them to better pastures, even if he has the means and can find the feed. He waits day after day, hoping for rains which do not come, until his stock begins to die from starvation. Then it is too late to remove them to new pastures, for experience teaches that working or driving starving animals is invariably productive of tremendous losses.

It is in an emergency of this kind that the prickly pear and other forms of cactus become a boon to the rancher. It is owing to the existence of the prickly pear that the success of the rancher in southern Texas is largely due. A score of ranchers have acknowledged to the writer during the past year that were it not for pear they would have to move their cattle out of the country once every four or five years on account of droughts. Theoretically, a rancher can safely stock his pastures to their capacity during the years of poorest production only, for the weakest link in his monthly chain of feed measures his strength in the stock business. For what matters it if he can accumulate a herd of 500 head of cattle, if a six months' drought causes a loss of 30 or 60 per cent in his herd?

With plenty of pear or other cacti in his pastures, however, this danger is largely removed. He has in this crop a feed which does not deteriorate if not used for three or four or even ten years; it is as good at one time as another, and can be fed by him at a couple of days' notice under any circumstances, although it is the general belief that it is much more valuable in winter than in summer.

A brief report of feeders in various portions of southern Texas will be to the point at this juncture. None of these has accurate accounts of his feeding. Everything is pure estimate, almost entirely from memory, but the accounts which follow are based upon statements of responsible feeders, whose estimates are as accurate as could be obtained without definitely planned experiments. Their experiences are of great value in planning future investigations and in suggesting to those who have not had experience how best to proceed in feeding these plants.

The Messrs. Furnish, of Spofford, Tex., have fed pear three winters. Two years ago they simply cut the cactus with a pear cutter and fed it in troughs with two pounds of cotton-seed cake a day for each animal. The following winter they scorched it with brush in the field and then chopped and fed it in the same way. Their experience appears to indicate that chopping does not destroy the spines sufficiently to prevent injury from them. During the first year they were feeding pear they lost many calves and they attributed the loss to this cause. They are confident that there is no danger for older stock. They experimented with a pear burner, but were not pleased with it, as their machine used up about a gallon of gasoline per hour under careful manipulation, and with the employment of cheap Mexican labor, much more. They discarded their machines and put the men at work singeing with brush, which, on account of the irresponsible labor available, they considered much more economical.

There are various ways of harvesting cactus. These people employ one or two men to cut the pear off with a hoe, and then another gang comes along and loads it on a wagon fitted usually with a hay frame. The felled pear is handled with forks, and from a ton to a ton and a half constitute a load. This is then hauled to the machine and chopped up. A machete is sometimes employed for cutting the cactus off at the ground.

It is claimed that the old stocks are much more nutritious than the younger joints. An effort is made, therefore, whenever extensive feeding is done, to go into the thickest, rankest pear areas and cut the plants off at the surface of the ground in order to get as much of the old stumps as possible. What relation there is between the young joints and these older stocks should be determined chemically as soon as possible. In practice it is always considered that the older joints and stalks are most nutritious.

The chop is loaded on to wagons and hauled to the feeding lot, where it is fed in large flat-bottomed troughs, 3 feet wide and 8 inches deep, the cotton-seed meal being sprinkled over the chop at the rate of about 2 pounds for each animal a day.

The first winter feeding was done steadily for two months, and the cattle were given all the pear they would eat, together with 2 pounds of cotton-seed meal. All stock had a limited run of brush pastures. After this first period of two months was up they fed a bunch of the poorer animals for two or three weeks longer until they got strong. These were then turned on to native pastures to "rustle" for themselves, while another bunch of weaker ones was fed two or three weeks longer. It is a very common practice throughout the pear region to feed only the poorer stock. The herd is worked over every few days for the purpose of cutting out those animals which are weak and most in need of feed. These are fed until they get on the mend, and are then turned out to "rustle" for themselves in the pastures, while another bunch is fed in their place. Very often all that is attempted is to keep stock alive until grass begins to grow.

Pear is considered good roughage in time of need in this vicinity, although no one regards it as a nutritious feed and all prefer to give even the stock which they are only attempting to carry through the winter some concentrated feed with it. It is impossible to estimate the total quantity of pear fed by the Messrs. Furnish.

Three years ago Mr. M. T. Cogley, of Laredo, Tex., fed 40 head of cattle for ninety days on a daily ration for each animal of 1 quart of cotton-seed meal, increased to 3 quarts as feeding progressed, and 200 pounds (estimated) of pear, chopped with machetes. Three men did the feeding and hauling. The animals fattened well, but it is believed they were held too long for the best results. They are supposed to have weighed about 50 pounds less than would have been the case ten days earlier. The falling off is thought to be due largely to too prolonged feeding of cotton-seed meal, but also to some extent to wet weather, which made the pastures boggy.

Mr. T. A. Coleman, of Encinal, Tex., is among the most extensive, if not really the largest, feeder of pear in Texas, and his experience is as varied as any in the country. His feeding has been done both to save cattle and to fatten them, and both operations have been conducted with uniform success. During the past winter four methods of feeding were employed:

(1) One lot of steers was fed in a closed pen. When feeding began they were given 3 pounds of cotton-seed meal, which was gradually increased to 6 pounds as the feeding progressed. The pear they ate was chopped and fed to them in troughs at the estimated rate of 80 pounds to a feed, or 160 pounds a day. During the last ten days each received about 8 pounds of sorghum fodder a day. The feeding continued seventy days, and Mr. Coleman and his men assert that they never saw stock fatten in better shape than did these; while Mr. Cameron, a buyer with a varied experience, authorizes the statement that they were far above the average of fleshy cattle in that section.

(2) In one pasture, cattle were fed pear scorched with a gasoline torch and were allowed free access to cotton-seed cake in a self-feeder. The cake feeding in this experiment was especially unsatisfactory, and the use of the self-feeder will be discontinued. These cattle had the run of dry grass pasture in addition to the cake and pear fed.

(3) A third lot was fed cotton-seed cake in a self-feeder, and allowed

the run of dry pasture containing an abundance of pear, of which stock eat a great deal during the winter without any preparation whatever.

(4) A fourth lot was fed similarly to the first, except that only one-half of the amount of meal was used. These cattle were held in a large pasture also.

The first of these methods is said to have proved by far the most satisfactory. Some idea of the extent to which pear is resorted to in times of drought can be had from Mr. Coleman's operations during the drought of 1901–2. From the latter part of November to the 5th of May, four pear cutters and twenty pear burners were in constant operation. Besides these, there were employed as many as 50 men, who traveled through the pear thickets with machetes, cutting the pear down so that cattle could get into it and feed upon it without further preparation.

In some respects Mr. Samuel Wolcott's experience has been as varied and definite as any which has come under the writer's observation. The methods which he has finally adopted for his work are considerably at variance with the practices of other Americans. Instead of using machinery, he chops all the pear he feeds with machetes, and all pear is scorched on a brush fire just enough to take off the thorns. His method increases the labor of handling considerably in some ways; but having to entrust the work largely to an unintelligent class of labor Mr. Wolcott believes that the additional expense of using machinery with such labor would be greater than the additional cost of using the machete and brush fires.

It has been his practice, in feeding for beef, to turn the stock into a pasture of considerable size in the morning; there they get a large picking of grass and some browse. While they are in the pasture the day's ration is prepared. The troughs are cleaned and filled; the pear is singed, put in the troughs, and chopped, and cotton-seed meal is sprinkled over it at the rate of from 3 to 6 pounds for each animal. It was the practice during the past winter to feed 3 pounds for thirty days, 4 pounds for thirty days, and 6 pounds for thirty days, making in all ninety days' feeding. It requires about ten days to get the cattle into the habit of eating out of a trough, so that the feeding period really extends over a period of about one hundred days. In reality the feeding period is governed largely by the condition of the feed in the pastures. The cattle are turned out on to grass after ninety days of pear feeding. One pasture is reserved for finishing cattle which have been fed pear and cotton-seed meal during the winter. This pasture is, therefore, always in good condition; but the intention is to feed so that the period of ninety days will be up about the time that grass is in good shape in the spring. The cattle are marketed off of grass.

The feeding of 125 head was done by three Mexicans and a foreman. Were it not for cheap labor the cost of pear feeding in this way would be considerable. With cheap labor, however, even this method is profitable in average years. This spring, cattle were fed on grass for two months after the pear feeding, but in an average year they are sold after four weeks' run on grass. The reason for the longer period this year was the prolonged drought of the spring season, which made pear feeding much less profitable than usually is the case.

It is Mr. Wolcott's practice to ship off grass or some other than the pear and meal ration, on account of the large shrinkage which the stock suffers after this kind of feed. If it were possible to furnish a partial ration of hulls to supplant a portion of the pear, he thinks that feeding would be very much more satisfactory; but it is to get rid of the expense of the hulls that the pear is resorted to.

In all cases in southeastern Colorado, as in Texas, only a partial ration of cactus has been fed. In some cases the remainder of the feed has been supplied in the form of corn chop, and in others cattle have had the run of poor pastures, as is almost universal in Texas. Mr. E. M. Bages, of Trinidad, Colo., during the past winter fed his 40 head of cattle 1,000 pounds (estimated) of cactus per day. He states that the pastures were so short that all the cottonwood leaves (*Populus* sp.) which had fallen during the past winter were cleaned up. They, however, got some grass as well as greasewood (*Sarcobatus vermiculatus*) and shad-scale (*Atriplex canescens*) browse. His practice was to gather one load of about 2,000 pounds of cactus on alternate days. The spines were singed off over an open fire of dead poplar wood. The stock were in poor condition when the ranch was visited, about the middle of April, but it is very questionable whether they would have been able to live at all without this additional feed.

Mr. J. M. John, of Trinidad, Colo., who is the only person in this country known to have steamed any of the cactus plants for cattle, reports that he had good success one winter in feeding daily to each animal 30 pounds of steamed cactus and 4 pounds of corn chop, together with a small ration of hay. A lot of poor cows was made into beef between the first of January and the middle of April upon a somewhat larger ration than the above. These data, while not so definite as one could wish, are suggestive and form a splendid basis for future work.

PEAR AS A HOG FEED.

While several reports have come to us through the Agricultural Gazette of New South Wales regarding the feeding of prickly pear to hogs, there appears to have been but little attention paid to it for this purpose in this country. The only place known to us where pear has been fed successfully to hogs is at the asylum in San Antonio, Tex. The feeding here is done in such a way that the data, while valuable, give very little idea of the amount consumed by each animal. The results obtained appear to indicate, according to Mr. J. F. Branham, that hogs take to the pear for roughage as kindly as cattle.

The number of hogs fed on the place during the past year and a half has been in the neighborhood of 230 in all. Many of these were small and ate little or no pear. To this number of animals, during a period of one and a half years, were fed 400 bushels of corn, 2½ barrels daily of meat and bread scraps, and 3,000 pounds daily of pear.

In feeding, extreme care is said to be necessary to rid the pear of spines, for they are very injurious to the hog. During this feeding about one-half of one per cent was killed by the spines in spite of the great precautions exercised. The pear was all burned in the field by a gasoline burner, loaded on wagons and thrown into the pens, one man burning as fast as three men could cut and load. Each day's ration of 3,000 pounds required 2½ gallons of gasoline for the burning.

In many localities in the pear region of Texas it is the practice, as soon as the tunas (fruit) ripen and begin to fall off, to let out the few hogs which the rancher usually has to feed upon them. It is considered by all who have had any experience with this practice that hogs are very fond of these fruits, and fatten very rapidly upon them.

PEAR FOR SHEEP AND GOATS.

Mr. Albert Urban, one of the largest owners of sheep in the Laredo district at the present time, values the pear very highly. His sheep are run entirely without feed, even during the dry seasons. His pastors all carry machetes and cut the edges off of the joints to give the sheep a chance to get at the pulp without being injured by the thorns. His range is well adapted to sheep on account of the large amount of browse furnished by the guajilla (*Acacia berlandieri*) and the mesquite (*Prosopis glandulosa*). These, together with the pear chopped with the machete, furnish an abundance of feed when the grasses fail, and the latter obviates the necessity of driving to water as often as would otherwise be necessary.

Upon nearly every ranch of any note in the pear region a small flock of goats are run and held most of the time in the thickest pear and brush on the ranch. It is a universal practice to furnish them access to all the pear they will eat, by a liberal use of the machete. The amount of pear they consume depends upon the condition of the other feed, it furnishing the greater part of their ration during droughty seasons.

PEAR AS A RATION FOR WORKING ANIMALS.

The animals best adapted to working on pear appear to be oxen. They often work for months upon no other feed than dry grass, brush, and prickly pear. Instances of the use of scorched pear for oxen by the early freighters have been mentioned. Even now a large number of Mexican wood choppers in the extreme southwestern part of Texas use no other feed than pear and what grass or browse the country affords. Often the grass and browse are very small in quantity. These people simply scorch the thorns off with brush, although many of them do not even go to this trouble, as they simply slash into the plants with a machete enough to give the animals a start into the clumps.

Mr. T. A. Coleman finds that oxen can be used with great economy in feeding pear to cattle. His machines are set in a pear thicket, and the distance hauled during the past winter was an average of about one-half mile for the round trip. The pear was hauled to the machine by two four-ox teams, which hauled 36 to 40 loads a day, an average load weighing 1,500 pounds (estimated). The travel per team, according to this, was about 10 miles per day. The last load cut each day was placed in a trough in a small pen for the work oxen, and they always had all they would eat. They got no other feed and kept in good working condition during the entire feeding period.

There are hundreds of ox teams in the southwestern part of Texas that work all the year on a ration consisting very largely of pear all of the time, and practically nothing else for months. They belong mainly to the Mexican population, who freight and haul wood to the towns, ranches, and pumping establishments which are springing up somewhat numerously in that section. Their ration consists of such feed as the country produces. Grass and browse are the main feed when the seasons are good. It is during the dry seasons that the greatest quantity of pear is fed, but the freighter never omits it from his ration for working oxen. Even during the month of May, 1904, when grass was in the best possible condition and there was an abundance of it, pear scorched with brush was regularly fed. It is impossible to tell how much these animals eat.

A day spent upon the market plaza at Laredo, Tex., confirmed the statement which had been often heard regarding the large use made of pear by the Mexican wood choppers. When the men are asked what they feed, the answer invariably is "nopal" (prickly pear). One, of whom special inquiry was made, stated that he was hauling wood 30 miles (round trip), making two trips per week. His loads averaged three-fourths of a cord of mesquite wood. His oxen grazed very largely on grass at that time, but the greater part of the year they got little besides nopal, the thorns being singed off over a brush fire. His team was in good working condition.

The largest amount of freighting in the State of Texas at the present time is doubtless done below the line of the Texas and Mexican Railway. In this region there is an abundance of pear of good quality. Here, and in fact farther north, especially along the Rio Grande, teaming is still a business; but it is almost entirely in the hands of the

Mexican population, who own their oxen and carts, their sole holdings in many cases.

It is estimated by Mr. Jacobo C. Guerra that there are no less than 200 of these Mexican carts operating between Rio Grande City and the north. About 60 of these work at the business continuously, while the remainder haul when there is an exceptionally large quantity of freight to be moved. There are a few mule teams on the road, but by far the larger quantity of freight is hauled with bulls or oxen; even cows are sometimes hitched to the wagons. A team consists of 4 to 10 oxen hitched to a Mexican cart. Such a team will make a trip of 76 miles and back in ten to fourteen days. The longer time is the one most frequently used. Two trips per month is what the average team makes. They go practically empty one way, and haul 3,000 pounds on the other trip. This figures up, for those who work at the business all of the time, 10 miles per day, continuously, from one year's end to the other, and this over a very hard road, two-thirds of which is sandy. This work is done by these animals upon a ration of prickly pear and grass, when the latter is to be had; when there is no grass, pear alone suffices. There are long seasons of frequent occurrence when grass is next to nothing, and during these seasons nopal in large quantities is fed, the cattle getting little else. The season is both infrequent and severe when the hobbled ox can not get some feed out of a brush pasture. Frequently, however, the feed, aside from pear, is very small in quantity.

Probably the largest amount of teaming is done between Hebronville and Rio Grande City. There is no pear convenient upon the northern one-third of this road. It is therefore necessary for the teamsters to provide themselves with pear by hauling it over about one-fourth of the journey. This necessitates the hauling of pear 15 or 20 miles, which largely increases the total work done by the animals. The driver camps at night in a pear thicket, lights a brush fire, and in about thirty minutes scorches the thorns from enough pear for his team to eat during the night. Another feed in the morning is usually all they get. In some cases the animals are given a ration of pear at midday. These people are often provided with a pear fork, a description of which has already been given (see fig. 1, p. 15), while some of them use a sharp stick for handling the pear. In chopping the pear down an ax or a machete is used. Before leaving the pear thickets enough pear is scorched and loaded on the wagons to feed the teams until they return to the thickets again.

During a good season, like the past one, there is plenty of grass along the road, but in spite of this pear is fed. The animals do not eat so much of it as they do when the grass is short, but there is never a season when they will not eat a surprisingly large amount of scorched pear.

During long, dry seasons the water supply along the road becomes very scarce, and teams often are forced to make the entire distance of 76 miles without water, on a full ration of pear. Indeed, teamsters have informed the writer that during the winter their oxen drink only about once each week, but that they need water two or three times a week during the summer.

It is next to impossible to get a very definite notion of how much these people feed their stock. As accurate an estimate as it has been possible to secure allows one-half load of singed pear to 12 head of oxen for one feed, when two feeds a day are given the animals. A load will probably weigh from 1,500 to 2,000 pounds.

EFFECT OF PEAR UPON STOCK.

The views of ranchers are so much at variance regarding many points relating to cactus feeding that it is impossible to form a definite opinion regarding many features of the practice. There is a comparative unanimity, however, upon many points. There is need of experiments for their verification, for popular experiences and opinions are too indefinite and unsatisfactory.

Stockmen are very generally agreed that pear should be fed very gradually at first, many claiming that a week should elapse before a full ration can be safely fed. The reasons for this, however, will vary with the individual and the locality. Mr. Sinclair has abundant evidence that bloat is very easily caused in cattle that are not accustomed to the feed. Really, cattle look as though they were bloated after every feed, for the quantity eaten (125 to 200 pounds a day) is bound to cause a large distention of the stomach; but there appears to be no danger after the animals have become accustomed to eating it.

Stock fed on a full ration of pear scour more or less all of the time, and the injury from this source is of course very much aggravated if the cattle receive rough treatment. A half ration, with some drier roughage, such as sorghum hay, or even dry grass or browse, appears to produce less serious effects. This condition could not be otherwise with such sloppy feed. It occurs invariably with beet pulp, and the effects are probably very similar.

The condition of stock which have received pear during the winter appears to be very much better than that of those wintered on good dry-grass pastures. Feeders without exception make this observation. The experience of the Glass Brothers is very conclusive in this regard. In the winter of 1897 their pastures were so short as to necessitate their moving their cattle to rented lands, not, however, very far away. In the herd were 55 pregnant cows, too poor to be moved. These were held on the home pastures and fed pear chopped with machetes, together with 1 to 1½ pounds of cotton-seed meal daily. These animals were turned on grass on the 17th of March, and could have been sold as grass-fat cattle in sixty days, while that portion of the herd wintered on dry grass was not fat until fall. Of course the effect of moving and the influence of the pound or pound and a half of cottonseed meal must not be overlooked, but the influence of the pear was certainly very potent. This corresponds very well with the experience of feeders in southeastern Colorado, where cactus is commonly fed without any other feed except what stock pick up in native pastures. Here it is found that cactus fed in any form is of decided advantage in toning up the system, particularly of 2-year-old stock, which suffer especially on account of the condition of their teeth at this age. Many 2-year-old heifers upon the range are lost at this age from constipation, brought on, no doubt, by a long-continued diet of dry grass, which is often so short as to be difficult for stock of this age to get at it. This evil, it is said, is corrected by a few feeds of cactus.

Ranchers in Texas often lose a small number of cattle from the effect of the accumulation of fiber of the pear in the stomach. This condition is said never to occur with chopped pear, but to be common in cases where a pear burner or machete is used, and still more common in cattle which are forced to eat a large amount of pear in short pastures during dry seasons. The balls are said to be made up entirely of the fiber and spines of the pear. It is also claimed that fiber balls are never formed when stock have a reasonable quantity of grass or other roughage with the pear.

No manner of feeding cactus yet devised, without greater care than the feeder is usually willing to bestow upon the work, does away entirely with the evil effect of the spines. Singeing with a torch or brush is the most effectual in this regard, if sufficient care is taken by the operator. In practice, however, very little attention is paid to the small spines, the effort being to burn off the distal three-fourths of the large ones, leaving most of the small ones for the stock to contend with. Indeed, there is a prejudice—whether well founded or not it has been impossible to determine -against pear scorched to the extent necessary to insure the removal of all the small spines. It is claimed that cattle scour much worse upon pear which has been excessively scorched by either torch or brush flame. Another objection urged is that torch-scorched pear invariably dies if the flame is kept upon it long enough to insure the removal of all the spines. This is really an important matter for those who have but little pear in their pastures, as simply singeing off the larger spines does not check the growth of the plants at all, and all the singed plants not actually grazed grow the following season.

The spines invariably work into the skin and flesh of animals which have the run of pear pastures to a large extent, certain exposed portions of the skin being often literally filled with them. It is reported by butchers that they often find cattle and sheep so full of cactus spines that their skinning knives are dulled by a few strokes, on account of the large number which penetrate through the skin into the flesh, requiring the cutting of thousands of spines in the skinning. Inquiry made among hide merchants at several places does not indicate that they recognize any deterioration at all on this account. They invariably report that they take no cognizance of this defect in their classification of material brought to them, although they admit that the value is sometimes slightly reduced.

It is invariably the practice, wherever chopping machines are used, to feed the chop as soon as it is cut. A rapid fermentation sets in usually within twelve hours, but the rapidity and time are dependent upon the condition of the atmosphere. Authentic cases of injury to cattle by the use of fermented chop have not been found, but feeders report that they dare not feed fermented pear on account of an apprehension of injury which it may do. Rather than run any risks the rancher prefers to feed immediately upon cutting. The process of fermentation is a very peculiar and interesting one scientifically, and of course has a decided economic bearing. There appears to be a great deal of difference in the behavior of different species in this respect, judging from specimens put up for museum use and for chemical analysis. Some joints dry quite naturally in a relatively short time, while others begin to ferment very soon after being removed from the plant. The Texas species which are fed may be cut and piled in large heaps for from four to six weeks without undergoing any apparent change except a slight desiccation; but when chopped, the fermentation starts in very quickly. There are indications that some species at least ferment much more readily when cut in certain ways, and the cultivated forms more readily than the native ones. It is well established that fermented cotton-seed products produce serious effects when eaten by cattle, and the rancher who mixes these products with his pear must necessarily feed before fermentation has had time to take place. The well-known effects of fermented cottonseed products, and the rapidity, vigor, and nauseating effects of the fermented pear warrant the caution exercised by all who feed in this way.

CACTUS FOR THE SILO.

Attempts to prepare ensilage from prickly pear have been reported once or twice in the Agricultural Gazette of New South Wales, but, so far as the writer is aware, no definite results have been secured. The Messrs. Furnish, of Spofford, Tex., attempted it one year, but on account of the improper construction of the silo nothing came of the experiment.

There is but little use in the preparation of ensilage from cactus. One can always gather this plant in the green state at any time of the year, and the object of going to the trouble and expense of placing the material in a silo is not very evident. Apparently there is little or nothing to gain, and the expense is considerable. The only way in which this can be made profitable is to mix the chopped pear with some other much drier feed in the silo.

PEAR THICKETS AND THEIR DESTRUCTION.

It has been but a few years since the ranchers in the pear sections of Texas were inquiring anxiously for some method which could be successfully employed in ridding the native pastures of what was considered an absolutely worthless and injurious weed—the prickly pear. It was asserted that the pear, like the mesquite (*Prosopis glandulosa*) and guajilla (*Acacia berlandiere*), was spreading rapidly and would soon overrun and greatly injure, if not destroy, large areas of pasture land. But this was before the combination of pear and cotton-seed meal as stock feed was appreciated. To-day the occasion for the destruction of the pear does not exist, and an absolute destruction would be a calamity indeed. In some sections, however, the artificial propagation by cuttings, brought about by the liberal use of the machete, has thickened up the growth of the plants to such an extent as to make it advisable to thin the areas somewhat in order to give the grasses, which are very often impeded in their growth, a better chance, as well as to give stock a freer opportunity to get through the pastures and enable the herds to be worked to better advantage.

Some ranchers report that they have succeeded in thinning out the thickets in rather a simple way. An effort is made to allow as large an accumulation of grass and weeds upon the fields as possible, preparatory to the thinning process. When the vegetation is dead and dry, fire is set to the pastures at a time when it will run to best advantage. This is usually after the heavy frosts of early winter. The fire does not kill the pear, as a usual thing, but the spines are singed off from a great deal of it, giving the cattle which are turned in later a chance at the succulent forage. After the fire there is, of course, but little for stock to eat except the pear. Heavy pasturing is practiced and the plants are closely grazed, resulting in the removal of a large amount of stuff, usually without killing many plants. After such treatment it takes several years for the cactus to grow up again so as to influence seriously either the growth of the grass or the handling of stock. This practice is resorted to also in order to destroy some of the brush, which often becomes detrimentally thick. Some idea of the extent of brush and pear developments in some sections of Texas can be gained from the statement that it costs $15 to $20 per acre to clear land which it is said was a comparatively open prairie thirty years ago.

The practice of slashing the pear bunches with a machete, spade, or other instrument in the field is a questionable one in many localities where the cactus is already very thick. As stated above, large pieces of the joints, and often two or more whole joints, fall on the ground and are left there by the animals, they being able to handle the portion on the stem to better advantage. Some of these pieces die, but a very large percentage strike root and grow, thereby thickening the pear thickets unnecessarily. In some places the pear is already so thick as to interfere with grass production, and the condition is aggravated by the careless practice of slashing the pear in the field, thereby scattering it into unoccupied areas, where it takes root and thickens up, to the detriment of more valuable feed. With care on the part of the herder this could be very largely avoided. All that is really necessary in order to give the sheep and goats a good chance at the pear is to take off the edge of the big round joint. It is on the edge that the greatest number of the most offensive spines occur. Taking off this portion exposes the pulpy substance so that the animals can readily nibble it. However, instead of merely taking off the edge the careless pastor slashes right and left, with no object but to expose the plant to the animals. The result is as stated above. The pear is spread by this artificial means in areas where it is already too thick. This excessive cutting of the pear can especially be avoided in the feeding of sheep and goats, for they prefer, and it is the custom to give them, the younger, more tender joints. The remaining more solid portions of the plants are preferred for feeding cattle. So far as the writer is aware, no definite tests have been made of the comparative nutritive value of different portions of the plants, and it is therefore impossible to state just how much scientific foundation there is for the universal opinion that there is more nutriment in the old stems than in the young joints.

SPECIES OF CACTUS WHICH ARE OF FORAGE VALUE.

The Texas ranchers and the Mexican people generally recognize several varieties of the prickly year. One often hears the Mexican people apply such names as *nopal pellon*, *nopal agrio*, *nopal azul*, *cacanapa*, etc., which express certain characteristics that they recognize. The majority of people, however, recognize two forms, and will point with considerable uniformity to a tall, woody, round, and thin-jointed, thorny, usually single-spined form, maturing in late summer, as *cacanapa*, and all others as *nopal*. (See Pls. IV and V.)

The former, they assert, is better feed for horses than for cattle. The cacanapa is doubtless a distinct botanical species, but the other forms are probably variations of a single species. The best pear grows on the best land, and here the plants have much fewer thorns, as a usual thing. The so-called blue pear is also largely an expression of vigor, but is considered the best pear for stock. It is usually free from dead or diseased joints. However, there may be very good pear with no trace of the blue color which is recognized in certain forms.

In some localities the older portions of the plants are gray, while in others they are yellow. In the vicinity of Encinal the color is almost universally gray, while around San Antonio it is always yellow; but the latter is considered much superior to the former, which is recognized as blue pear by everybody.

From an economic point of view it matters little about the species until the time comes to establish plantations, when the rancher must know which ones are the best feed and which grow the best. Until experimental investigations determine some of these points the statement will suffice that any of the cacti which are large enough and numerous enough to be fed economically are probably good stock feed. Sufficient information is at hand to show that the flat-jointed forms may be fed indiscriminately, and references are made in this publication to experiences in the successful use of several of the long-jointed forms. It is known that during hard times stock will eat the giant cactus greedily when it is chopped up so that they can get at it. The question resolves itself, therefore, purely into one of securing enough material. Any cactus growing large enough to be fed with economy can be used as roughage, or as a succulent for milk production. Some forms are much better adapted for these purposes than others, no doubt; but we have little positive evidence upon this point except that the blue pear of Texas is said to be of greater value than any of the other forms of that region.

ESTABLISHING PLANTATIONS OF PEAR.

Only two or three ranchers have been met who have gone to the trouble of attempting to grow pear by the establishment of new plantations. The plan pursued by Mr. Alexander Sinclair has been a very simple one. The plants have been cut up into individual joints, and these have been scattered at suitable intervals upon the ground. The unequal evaporation upon the two sides soon causes the joint to dish, and new joints spring from its edges, while roots grow from the side in contact with the earth. If the growth is vigorous and normal, three new joints will be produced the first year, three or more the second, and so on, giving a sufficient crop to pay for harvesting in four or five years from planting.

Mr. Sinclair's plantings have been a success in a measure. The areas are well set, but much of the pear is unhealthy, owing to the effect of parasites of both insect and fungus nature. This form of planting is the most simple and least expensive that can be devised. Much experimentation will be necessary to determine the best method of establishing plantations.

YIELD OF PEAR.

During the winter of 1902, Mr. J. C. Glass, of Eagle Pass, Tex., fed pear (Pl. IV, fig. 2) to save his herd, as is the common practice in Texas during drought. The number of cattle that were fed was not constant, for the herd was continually worked over, strong ones being turned out and weaker ones put on feed. When the drought was broken 1,500 cattle were being fed, and an average of not less than 800 were fed for the entire six months. The pear machine was moved into a pear thicket, near a windmill supplying an abundance of fairly good water for this region. It is believed by Mr. Glass that pear was not hauled over a quarter of a mile, and that not more than 80 acres were harvested. The area fed is irregular, the cutting being governed by the quality of the pear, ease of access through the thick mesquite brush, etc. The harvesting was done very closely in places and less so in others, the plants being cut off at the surface of the ground very often, but at other times much was left in the brush. The above count and estimate, therefore, represent, as closely as such estimates permit, the entire yield of pear on a virgin tract—virgin except in the quantity—which had been grazed by stock during the past fifteen or twenty years. This amount, however, is inconsiderable. These data are not definite, but they are the best available, and represent the practices in vogue in prickly-pear regions. Several things should be borne in mind in connection with this account. The conditions might be grouped, in order to present them clearly, as follows:

(1) The feeding was begun after cattle had begun to die.

(2) Feeding was practiced to keep cattle alive, not to fatten them.

(3) The pastures were worked continually, and a watch was kept for weak cattle.

(4) The stronger cattle in the feed pens were constantly being replaced by weaker ones from the pastures.

(5) From 1 to 1½ pounds of cotton-seed meal were fed to each animal, in addition to all the chopped pear it would eat.

(6) All except the very weak cattle were allowed the run of the pastures.

It will be seen from these statements that the stock obtained some feed in addition to the pear and meal, even from the brush pastures where they were dying before the feeding began. No attempt was made to do anything but keep the animals alive until the drought was broken. An effort was made, however, to give the cattle all the pear they would eat. As nearly as can be estimated, therefore, 80 acres of excellent pear furnished a full ration for an average of 800 head of cattle for a period of six months.

BEHAVIOR OF PEAR AFTER HARVESTING.

It is very difficult to get accurate notions of the time that must elapse between successive harvestings of pear even in southwestern Texas, where feeding has been so extensively practiced. The best observations which it has been possible to make thus far were upon the property of Mr. J. C. Glass. As previously stated, harvesting was done very closely upon some portions of his pasture during the winter of 1902–3. It is still too early to tell how long it is going to be before the area can be harvested again. It may be said, however, that about the middle of the second growing season after the harvesting there was abundant proof that the pear will be as thick as ever upon this area. It was observed that many of the old bunches were dead where closely cut. However, the vast majority of them had a joint left somewhere which was growing thriftily, and many joints broken off and left lying on the ground were starting new plants. It is estimated that it will take not less than five years to make a crop which it will pay to harvest. The pear, like everything else, depends upon the season, and the growth is directly proportional to the rainfall.

Several areas have been visited which have been harvested twice during the past four years, but in no case was the crop taken off clean. The best of the virgin crop was taken off one year, and more was harvested two or three years later. These areas, therefore, furnish no data regarding the time necessary to produce a crop. The method of harvesting has a decided influence upon the future growth. It is hard work to secure all of the old stems of the prickly pear, and they are also harder to chop than the younger joints. If only the younger joints are taken off, the old stems grow very vigorously the next few years, and produce a crop much quicker than when chopped off at the surface of the ground; but the feeder invariably desires as much of the old stems as possible.

Mr. Morrill Porr, of San Antonio, estimates that a small area which he planted several years ago can be profitably harvested for dairy purposes every two or three years. This seems a very short time to produce a paying crop of this plant.

OTHER ECONOMIC ASPECTS OF THE CACTI.

The large economic group of cactus plants, which is peculiarly American, has not received in this country the attention it deserves. (See Pl. IV, fig. 1, and Pl. V.) Some of the species naturalized in the Mediterranean countries of three continents form the main article of diet of millions of people during one or more months of each year. Some of the improved forms have been introduced from the Old World into this country. Throughout the Southwest and northern Mexico it is a common and familiar sight to find gigantic forms of the prickly pear 15 to 20 feet high about the old missions and upon the larger ranches and haciendas. (Pl. IV, fig. 1.)

The fruits are so highly prized by the Italians that there is a limited market for them in the larger cities of this country at the present time. They are imported from Italy, and sold at a price about equal to oranges, bulk for bulk.

The following rather formal list of the uses of these plants, together with what has been said in the body of this bulletin, will give some idea as to the use that is made of them by various peoples:

(1) The fruits of not less than a dozen Mexican species are delicious, and would form a valuable addition to our fruit supply. At least one-half of these are now growing out of doors in private collections of cacti in this country. (Pl. V, fig. 2.)

(2) Very palatable jellies are manufactured from the fruits of some species, and could doubtless, under proper commercial methods, be put upon the market as choice delicacies, if the plants can be successfully grown in sufficient numbers.

(3) The young joints are boiled for food by the Mexican people as greens.

(4) The young joints are manufactured into pickles.

(5) The young joints are chopped into small pieces and dried for future use.

(6) The expressed juices are used by the Mexicans for mixing with whitewash for exterior work.

(7) Many species are used for hedges, borders, fences, and other useful or ornamental plantings.

(8) The pulp of the group of cacti known to the Mexicans by the name of *visnaga* is boiled with sugar in the manufacture of cactus candy.

(9) The soft, pulpy tissues of cacti, being very retentive of moisture, are admirably adapted and extensively used for poultices.

(10) Some species yield valuable drugs.

(11) Before the development of the coal-tar dyes some of the species were largely used as hosts for the cochineal insect.

(12) The peculiar reticulations of the vascular system of many species are taken advantage of in the manufacture of an endless variety of art goods.

SOME CONDITIONS OBTAINING IN THE PRICKLY-PEAR REGION.

There is probably no locality in the United States where labor is so cheap as it is in the prickly-pear region. While it is a poor class, being largely of the Mexican peon type, and not so good, man for man, as the average American labor, wages are so low that many enterprises depending upon the price of labor can be undertaken there when they could not be established elsewhere. The average rancher in many parts of the region never thinks of doing his own hauling. So low is the price charged by the Mexican freighters that the rancher can not afford to do it himself. The rancher who feeds cotton-seed meal, for instance, buys it of his local merchant, who delivers it at the ranch, often 50 miles distant, the merchant adding to the selling price what he has to pay the local freighter, who hauls it either with oxen or mules, but usually with the former. Here we have the free-delivery system of the city, enlarged to apply to an area of country possibly 100 miles square; but, instead of owning his own teams and hiring his men by the month, the merchant contracts for the hauling with a class of labor that will do it cheaper than he can afford to do it himself. This class of labor has a very potent influence upon the utility of the pear as a cattle feed. Where pear is chopped with a machine there is considerable labor involved, the price of which, of course, governs the profit of feeding. If it is assumed that a crew of 8 men can feed 1,200 cattle—and this is a low estimate - the cost where pear is convenient is very slight with labor at the price that it is here. The itemized expense is about as follows:

Hire of seven men, at 50 cents a day	$3.50
Hire of one foreman	.75
Board of eight men	1.00
Interest on machine and engine per day, when operated four months per year.	.15
Gasoline	3.00
Total cost	8.40

The above is probably the minimum cost of a full maintenance ration of pear. In practice, a much larger number of animals can be fed with one machine if the cattle are allowed the run of pastures which contain some browse and dry grass, when the feeding is done simply to carry through a drought.

To the above must be added the cost of whatever meal is fed. As stated on previous pages, the majority of feeders who feed simply to maintain their herds through a drought give each animal 1 pound of cotton-seed meal in addition to the pear. With such a ration, stock make material gains in flesh and strength. Those who feed for the market in closed pens aim to give the stock all the pear they will eat, with a ration of 3 pounds of cotton-seed meal, gradually increased to 6 pounds.

The average wage for a herder is $7 to $10 a month, and board. Formerly the latter consisted of a ration approximately as follows: Two sheep or goats, 40 pounds of corn meal, 4 pounds of coffee, 4 pounds of sugar, and 6 pounds of frijoles. At the present time wages are a little higher, but still not over $12 to $15, with possibly a more liberal bill of fare. A very common practice is to hire for a stated period, for instance, for one year, at $12 or $15 per month, with a forfeiture of $3 per month if the servant quits before the end of the stipulated time. During dry seasons the rancher in southern Texas has no difficulty whatever in securing help, for the poorer classes of northern Mexico are very needy at these times and are willing to work at as low a rate as 25 cents per day and board.

The gradual extension of the cotton belt into the pear region is destined eventually to have a very potent influence upon the feeding of pear for fattening stock. The use of pear with cotton-seed products is very much in favor. The development of the pumping projects, together with artesian water in some localities, while withdrawing some lands from direct grazing, will contribute nevertheless very materially to stock raising. The areas devoted to cotton culture will especially contribute a valuable support to the stock industry, and the cotton-seed products will find a ready local market. The pear, fed as a roughage, with these cotton-seed products deprived of the present high transportation rates, will add perceptibly to the rancher's ability to mature the beef which he has always been able to breed successfully but not always to fatten economically.

POPULAR POSTULATES OF CACTUS FEEDING.

Data secured from popular sources appear to warrant the following conclusions, many of which are reservedly stated; it is hoped they can be experimentally verified in the near future.

Prickly pear, although poor in nutritive quality, can be fed to decided advantage under several conditions and for several purposes:

(1) To save cattle during a prolonged drought, when other more nutritious feed is scarce.

(2) To fatten cattle, when employed as a roughage with more concentrated feed.

(3) When fed with more concentrated foods and some hay or pasture, it is a valuable accessory to the dairy ration; it supplies succulence which it is difficult to secure in semiarid regions a large part of the year.

(4) Oxen can be worked on a ration consisting very largely of pear for an indefinite period.

A full-grown steer fed on pear alone will consume from 125 to 200 pounds daily.

Mature steers, accustomed to a pear diet, can live in a pear pasture a long time without water.

Oxen worked on pear drink water two or three times a week in summer and once a week in winter.

A good milk ration of pear, with plenty of other nutritious feed, will consist of from 40 to 70 pounds of pear for each animal a day.

Pear, fed whole, especially when stock has little else to eat, is likely to form fiber balls and kill a small percentage of cattle during prolonged feeding.

Pear, when burned, scours cattle much worse than when it is simply scorched enough to take the thorns off.

Pear with many thorns is as easily prepared for the use of stock as that which has but few thorns.

It is quite probable that all the larger species of cactus can be fed to stock to advantage when properly prepared.

Prickly pear and other species of cactus may be fed in a variety of ways:

(1) Cattle accustomed to pear eat more or less of it during the entire year, whether there is plenty of other feed or not, and with no preparation.

(2) The thorns may be scorched off with brush.

(3) The thorns may be scorched off with a gasoline torch—a modified plumber's torch.

(4) The edges of the joints may be trimmed off with a machete, when stock, especially sheep and goats, gain access to the pulpy mass at an advantage.

(5) The plants may be piled in heaps in a field and chopped into small pieces with a machete.

(6) The whole plant may be chopped into pieces ½ to 1 inch long with machines prepared for that purpose.

(7) In some localities the whole plant is steamed in large vats to render the spines innocuous.

A cow, with calf, fed on prickly pear alone will lose flesh very rapidly.

Cotton-seed meal or cake and cotton seed appear to be well adapted to feeding with pear.

Hogs fatten well on the fruit of the prickly pear, and they take kindly to a ration of prickly pear when the thorns are properly singed off.

Stock fed on prickly pear and cotton-seed products are said to suffer heavy shrinkage on the way to market.

Pear as feed for stock is of sufficient value to warrant investigations for the purpose of determining:

(1) How it may best be propagated.

(2) Whether there are species in foreign countries of greater value than those which are native to the Southwest.

(3) Its exact value as food for both man and beast.

(4) The nature and cause of the rapid fermentation in the chopped material.

(5) The comparative value of different species.

(6) The comparative value of old and new growth.

(7) The exact influence upon quantity and quality of milk.

The old woody stems are preferred by feeders to the young joints. When fed for succulence, as is the case in dry weather, the young nopals (joints) are of more value than when a maintenance, or fattening, ration is desired.

Pear has been fed in Texas since the early Spanish occupation.

Pear is better feed from the time that frost strikes it in the fall until it begins to grow in the spring than in other seasons.

Cattle and working oxen will eat a large ration of pear, properly prepared, when there is an abundance of the best of green grass for them to eat.

Pear has a decided value in toning up the system of cattle that have lived on dry grass for several months. Two-year olds especially are benefited by a partial ration of it for a short time.

All cattle, sheep, and goats soon become accustomed to eating pear. The sound of the pear machine or the sight of smoke in the pastures where stock are fed attracts the entire herd immediately.

The different species and varieties of pear, while of value, differ in their feeding qualities.

The development of pear feeding will increase the utility of concentrated feed stuffs, such as cotton-seed products.

The greatest promise for pear is in the line of milk production. The value of the succulence for the winter months will probably pay for the propagation of small acreages for this purpose.

Burning with a pear burner tends to kill out the pear if close pasturing is practiced afterwards.

It is a mistake to harvest pear too closely unless it is desired to thin it out.

Pear makes sufficient growth in average seasons so that it may be harvested every five years.

When fed a full roughage ration of pear, cattle scour more or less all of the time.

There are four machines on the market for preparing pear for the use of stock—two burners and two choppers.

One man with a pear burner can feed 400 cattle in a brush pasture. The gasoline consumed will range from 6 to 10 gallons per day.

Ten men with a pear chopper can feed from 1,500 to 2,000 cattle under the same conditions.

Inquiry at hide establishments and stock markets fails to reveal any serious injury done by the spines to commercial cattle products, although the spines work into the flesh considerably.

Cattle fed on pear chopped with a machete, and not burned, often get their mouths so full of spines after a time that they are unable to eat at all.

The crushing action of the chopping machine renders the spines innocuous.

Chopped pear sours very quickly, and must, therefore, be fed very soon after being chopped.

Pear cut and piled up moderately will keep in good condition for a month or more, if not left in the sun.

There is no object in preparing ensilage from pear, even if it can be successfully done.

The pear has a large number of enemies, consisting mainly of insects and fungi. Rats and rabbits are also injurious in some seasons.

The pear has two characteristics which render it especially valuable for pastures:

(1) It can withstand long periods of drought without injury. It has limitations, however, in drought resistance. It has been severely injured during some droughts within the memory of the present generation.

(2) It is protected by spines, so that it can not be materially injured by overgrazing without artificial preparation. A thornless pear, in a pasture grazed the entire year, would soon be exterminated.

Pear is not particularly difficult to keep in subjection, nor is it spreading of its own accord to any alarming extent. However, to prepare a pear thicket for cultivation is expensive, for all of the pear must be hauled out of the field. It can not be burned like brush.

There are many areas in extreme southwestern Texas where pear is so thick as to interfere with the growth of grass. The feeding here should be done with the view of thinning the pear rather than destroying it.

The destruction of the pear in southwestern Texas would be a severe calamity to the stock industry.

The practice of preparing pear with a machete by cutting off the edges of the joints tends to form pear thickets, which is often disadvantageous.

In practice, pear is very seldom fed alone. Even during the severest drought cattle are able to pick up some old grass and get a little browse from the abundance of brush that exists throughout the pear region. It is seldom that the Texas rancher feeds it without some cotton-seed meal, although the cactus of southwestern Colorado has usually been fed alone.

Cacti have many uses besides that of forage.

Prickly pear, including several species in southwestern Texas, the cane cactus of southeastern Colorado and New Mexico, and the cholla and related species in one or two localities in Arizona, are the only species of cactus that have been fed to any extent in this country.

PLATES.

DESCRIPTION OF PLATES.

Plate I. *Frontispiece.* Old and new ways of singeing cacti. Fig. 1.—The cane cactus of southeastern Colorado, singed with brush. April, 1904. Fig. 2.—The prickly pear of Texas, singed with a torch. This is a typical illustration of the method largely employed throughout southern Texas of destroying the evil effect of the spines by singeing with a blast flame from a gasoline torch especially prepared for this purpose. Sinclair ranch, near San Antonio, Tex., May, 1904.

Plate II. The prickly pear and a pear machine. Fig. 1.—One of the common prickly pears of Texas in full fruit. This plant is bearing rather abnormally this year. Glass ranch, near Eagle Pass, Tex., May, 1904. Fig. 2.—A type of pear cutter as set up and operated by Mr. J. C. Glass two years ago. Machine as seen from the horsepower platform. May, 1904.

Plate III. Another type of pear cutter. Fig. 1.—Front view, showing knives, together with a sheet-iron shield which acts as a back stop for the pear, which is fed against the face of the revolving wheel. June, 1904. Fig. 2.—Rear view, with casing removed, showing the boxes behind the knives into which the chopped pear passes and is carried out of the machine. The delivery opening of one of these is shown on the left. June, 1904.

Plate IV. Fig. 1.—Nopal de Castilla, cultivated in southern California. Such a scene as this is common in the vicinity of the old missions and larger haciendas throughout northern Mexico and the southwestern United States. This plantation is doubtless upward of 30 years of age, and some of the plants are 20 to 25 feet high. Fig. 2.—A pear thicket on the Glass ranch, Eagle Pass, Tex. This is typical of large areas in this part of Texas. May, 1904.

Plate V. The Tapuna pear. Fig. 1.—A single plant of the Tapuna pear near Alonzo, Mexico. The fruits of this species are highly prized as an article of diet, and are about the first that appear in the markets of San Luis Potosi. The spines are not numerous and the joints are very thick and succulent. Alonzo, Mexico, June, 1904. Fig. 2.—Fruit of the Tapuna pear in one of the market places at San Luis Potosi, Mexico. June, 1904.

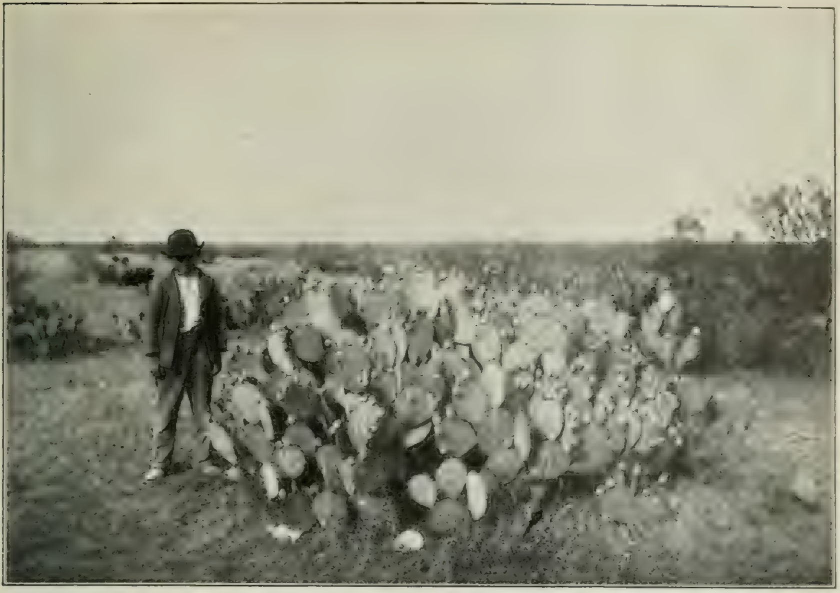

FIG. 1.—ONE OF THE COMMON PRICKLY PEARS OF TEXAS IN FULL FRUIT.

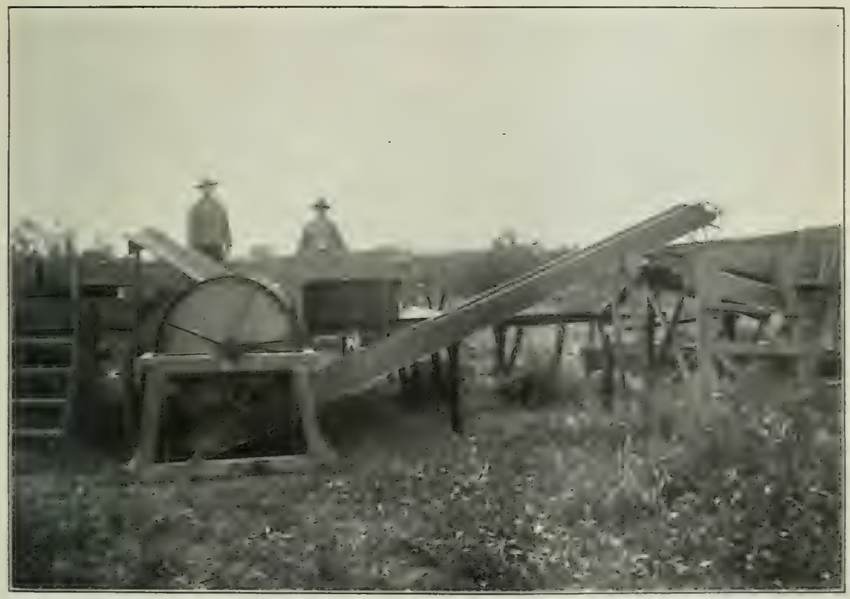

FIG. 2.—A TYPE OF PEAR CUTTER, AS SET UP AND OPERATED BY J. C. GLASS.

THE PRICKLY PEAR AND A PEAR MACHINE.

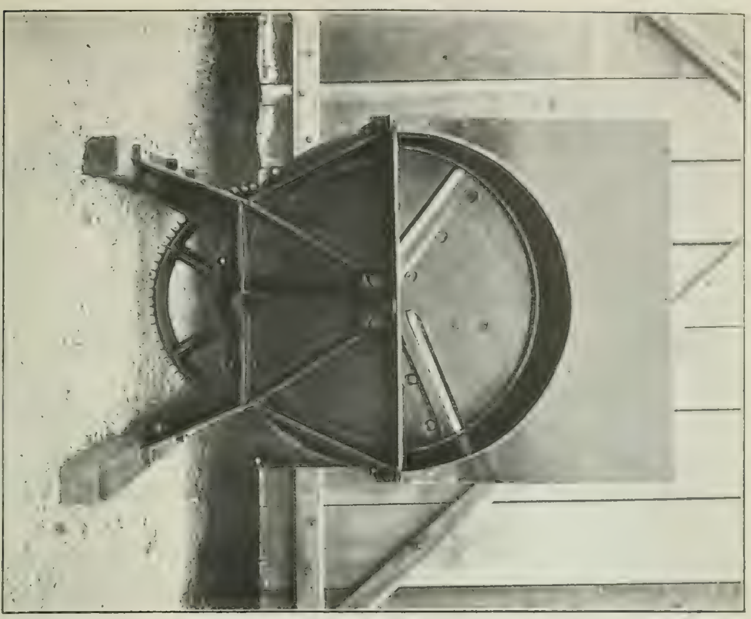

FIG. 1.—FRONT VIEW, SHOWING KNIVES.

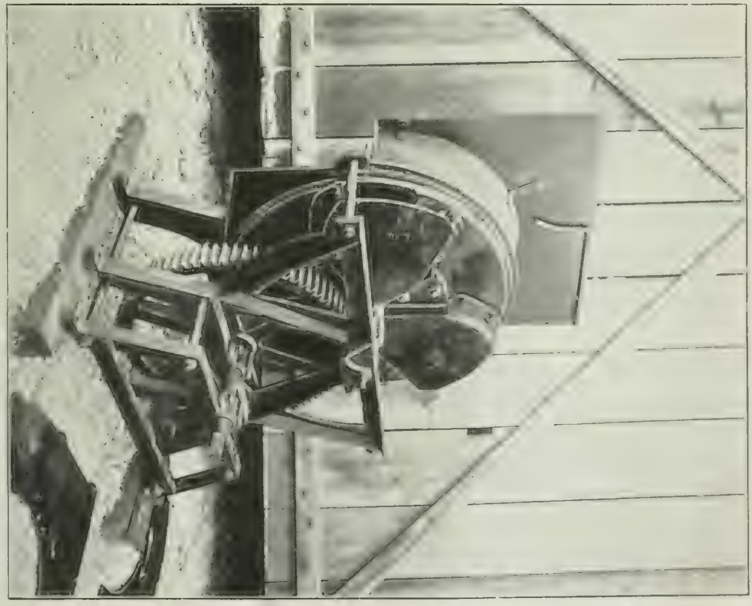

FIG. 2.—REAR VIEW, WITH CASING REMOVED, SHOWING BOXES BEHIND THE KNIVES.

ANOTHER TYPE OF PEAR CUTTER.

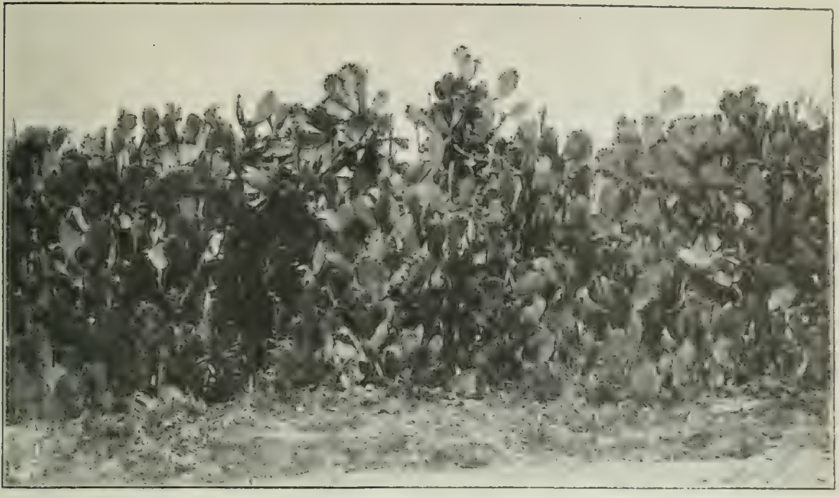

FIG. 1.—NOPAL DE CASTILLA, CULTIVATED IN SOUTHERN CALIFORNIA

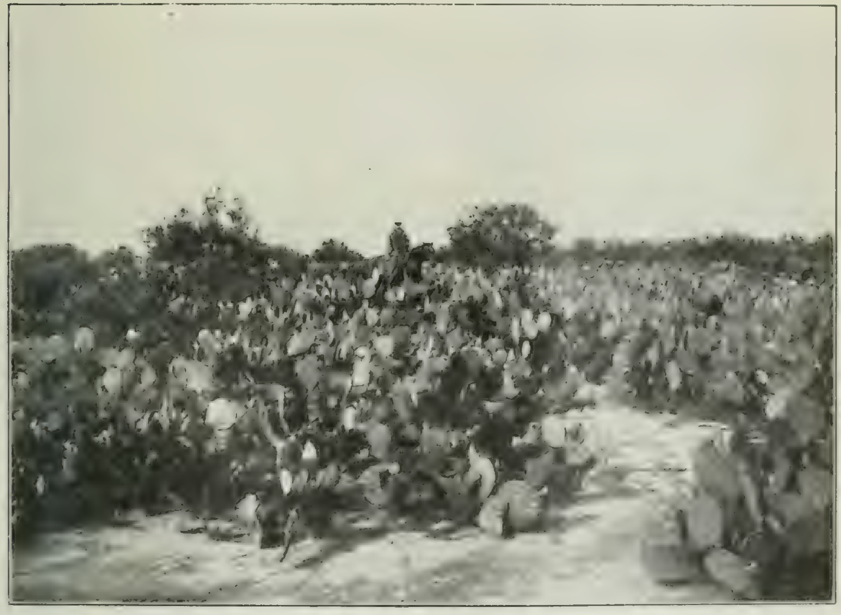

FIG. 2.—A PEAR THICKET ON THE GLASS RANCH, EAGLE PASS, TEX.

PRICKLY PEARS IN CALIFORNIA AND TEXAS.

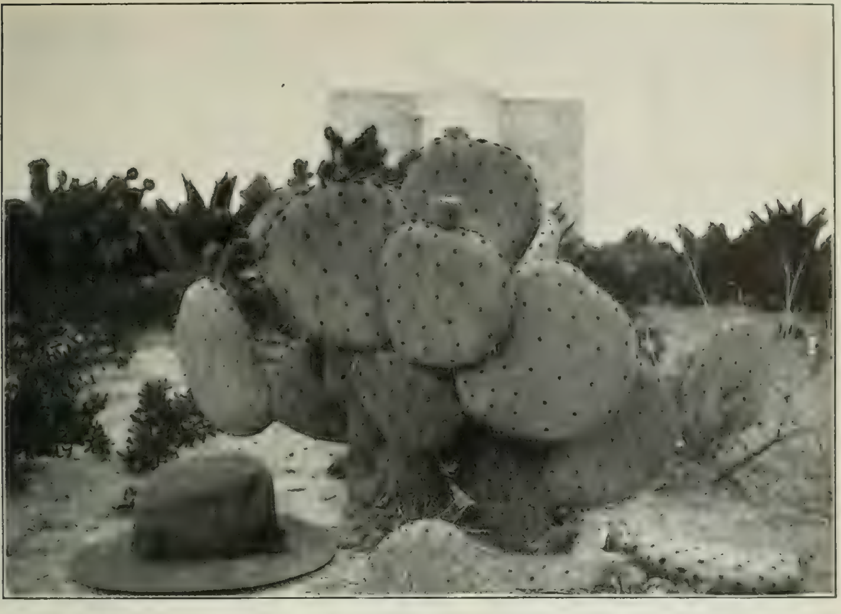

FIG. 1.—A SINGLE PLANT OF TAPUNA PEAR, NEAR ALONZO, MEXICO.

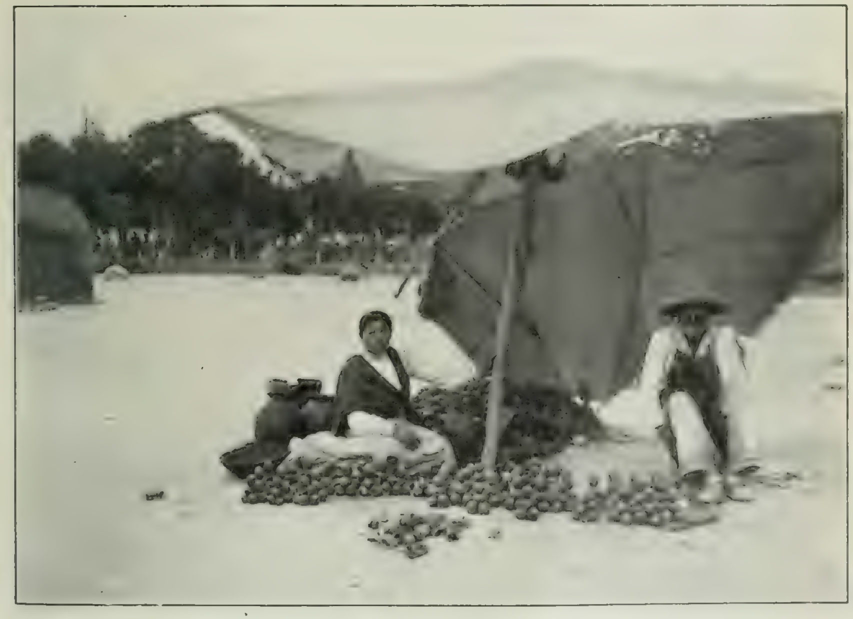

FIG. 2.—FRUIT OF THE TAPUNA PEAR IN ONE OF THE MARKET PLACES AT SAN LUIS POTOSI, MEXICO.

THE TAPUNA PEAR.

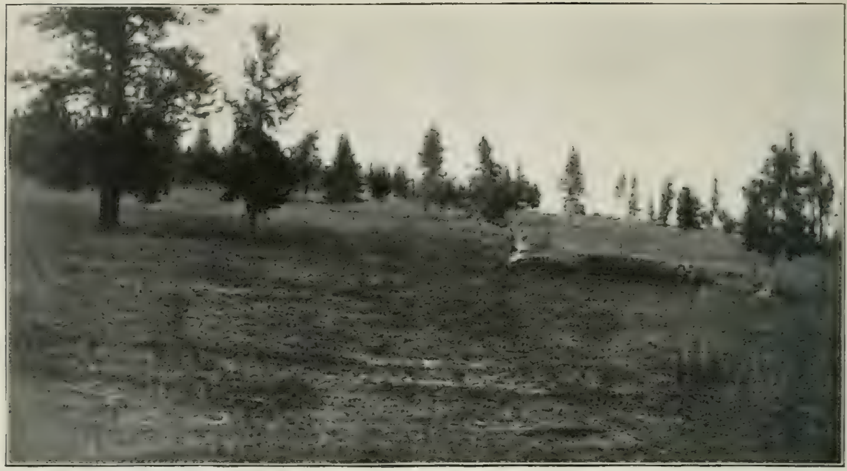

FIG. 1.—MOUNTAIN MEADOW WHERE TIMOTHY WAS SEEDED IN THE AUTUMN OF 1902.

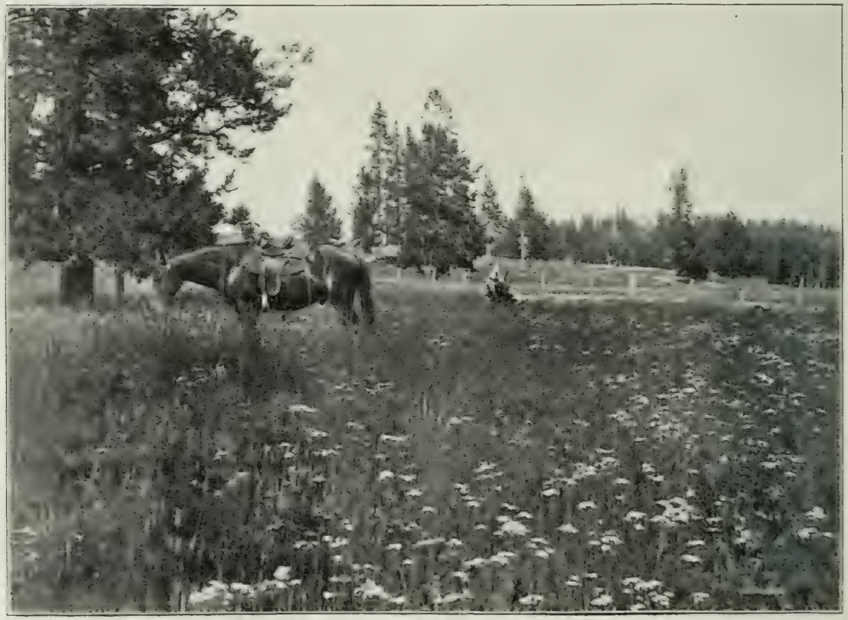

FIG. 2.—SAME PLOT SHOWN IN FIGURE 1, TWO YEARS LATER.

RANGE IMPROVEMENT BY RESEEDING.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 75.

B. T. GALLOWAY, *Chief of Bureau*

RANGE MANAGEMENT IN THE STATE OF WASHINGTON.

BY

J. S. COTTON,

ASSISTANT IN RANGE INVESTIGATIONS,
IN COOPERATION WITH THE WASHINGTON STATE
EXPERIMENT STATION.

GRASS AND FORAGE PLANT INVESTIGATIONS

ISSUED MAY 23, 1905.

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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY,
OFFICE OF THE CHIEF,
Washington, D. C., February 24, 1905.

SIR: I have the honor to transmit herewith the manuscript of a paper on Range Management in the State of Washington, which embodies a report upon investigations conducted in cooperation with the Washington State Experiment Station.

This paper is a valuable contribution to our knowledge of improvement of range lands, and I respectfully recommend that it be issued as Bulletin No. 75 of the Bureau series.

The accompanying illustrations are necessary to a complete understanding of the text.

Respectfully,

B. T. GALLOWAY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

PREFACE.

In the spring of 1901 cooperative arrangements were entered into between the United States Department of Agriculture and the Agricultural Experiment Station of the State of Washington for the conduct of investigations on range lands in that State. These investigations were inaugurated by the writer, who at that time was agriculturist of the Washington State Experiment Station, acting both for the station and for the Department of Agriculture, under the direction of the then Agrostologist, and the details of the work planned were carried out by Mr. J. S. Cotton, under the direction of the writer. This cooperative arrangement continued until the end of December, 1903. Since June 1, 1904, the work has been continued by the United States Department of Agriculture under the direction of the writer, the details of the work being again carried out by Mr. Cotton.

In 1901 experiments were undertaken on Rattlesnake Mountain, at a point 16 miles north of Prosser, Wash., with a view to determining what grasses could be established on the range by seeding by different methods. In October, 1902, similar experiments were inaugurated at the Wenatchee Mountain Station on the high range of mountains separating the Kittitas Valley from the Columbia Valley to the north.

In addition to the seeding experiments above mentioned, Mr. Cotton has spent much time in studying the methods used for managing stock upon the range throughout central Washington, and the accompanying bulletin gives the results of the seeding experiments and of Mr. Cotton's studies on range management. Some of the work has demonstrated that certain grasses can be established in favorable localities in a manner which is entirely practicable, while Mr. Cotton's conclusions regarding methods of range management can not fail to be of great interest to stockmen in that section.

W. J. Spillman,
Agrostologist.

Office of Grass and Forage Plant Investigations,
Washington, D. C., February 24, 1905.

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B. P. I.—153. G. F. P. I.—110.

RANGE MANAGEMENT IN THE STATE OF WASHINGTON.

INTRODUCTION.

Owing to the greatly lowered carrying capacity of ranges in the State of Washington, investigations were begun in the spring of 1901 to determine, if possible, what steps must be taken to preserve these ranges and what methods should be used to bring the badly overgrazed areas back to their original state of productivity. These investigations were carried on cooperatively between the Bureau of Plant Industry of the United States Department of Agriculture and the Washington Agricultural Experiment Station from that time until January 1, 1904, when the experiment station withdrew. Since that time these investigations have been carried on independently by the Bureau of Plant Industry.

In the early nineties the ranges were very much overgrazed, and owing to the overcrowded conditions were deteriorating very rapidly. In 1896 the Northern Pacific Railway Company, in order to alleviate these conditions, which by that time had become very serious, instituted a system of leasing the railroad land, or odd sections, of the grazing areas to the stockmen. The motive in leasing this land was to prevent the destruction of the native forage plants of the grazing areas, which meant the removal of the stockmen from that region and a consequent loss of traffic to the railway company. The first lease of this kind was issued on July 1, 1896. Between that date and June 13, 1903, over 300 leases, embracing about 1,500,000 acres of land, were issued, and at the present time the greater part of these ranges is under the control of private individuals.

While this system was bitterly opposed by some of the stockmen, it really proved to be of great benefit to the State at large, as it enabled those people who had homes in the grazing country to secure control of the railroad lands about them by means of a lease, and thus protect themselves from the ravages of nomadic stock. The more progressive stockmen immediately availed themselves of this opportunity. The nomadic stockmen—to protect themselves from each other and to prevent being forced out of the country—also leased grazing lands sufficient for their needs. Had it not been for the large numbers of range horses that were allowed to run at will throughout the entire year, and thus continue their depredations, this system would undoubtedly have proved very satisfactory.

Shortly after this leasing system had been inaugurated a heavy immigration to central Washington took place. This immigration, together with the discovery which had been made shortly before, that large areas of land previously supposed to be of value for grazing purposes only would grow wheat, caused a rapid settling up of this region. As a result, large areas of bunch-grass land were homesteaded and purchased, until at the present time nearly all the land that is smooth enough for cultivation is used in growing wheat, or is being prepared for that purpose. This rapid settling up of the bunch-grass land has forced the stockmen into the coulée and hill lands, too rough for cultivation, and into the true arid regions and the mountains. In the arid regions the range is also gradually growing less, a condition which will continue, as irrigation, owing to the incentive given it by Federal legislation, will be vastly extended in the near future.

The progressive stockmen, in order to keep pace with the rapid development of the country for farming purposes, which has resulted in the crowding of their stock into much smaller confines, have purchased railroad lands, and wherever possible they have also leased the State lands that are unfit for cultivation and have fenced them for grazing purposes. Many of the original purchasers of the range lands are now in a prosperous condition. Others, who have acquired their lands within the past two or three years, are finding themselves seriously handicapped owing to the badly depleted condition of these ranges. Although they have much more to contend with than those who purchased before the depletion of the ranges was so great they will with persistent effort and judicious management eventually be successful. Those who have been too slow to realize the changed conditions have found themselves without range land, and for the most part these men have been compelled to go out of stock raising as a business. At the present time there is very little free range land except in the high mountain areas, where the grazing season does not last more than five months, and in the Okanogan country.

In the Okanogan country, owing to the present laws, it is impossible to secure tracts of land larger than 160 acres. Upon so small an area no one can make a living, and settlers are therefore dependent in part upon the outside range. Fortunately for them the natural conditions have in the past protected the country from being made a wilderness by overgrazing. The winters are long and the snowfall is quite heavy, thus necessitating winter feeding. For this reason the range horses, which have been a very great factor in the destruction of the ranges to the south, are not found to any great extent in this region. The strong opposition of the cattlemen, together with the long feeding season, has also prevented sheep from gaining an entrance to any appreciable extent. Again, the cattlemen themselves have been limited in the number of cattle they could run on a range by the quantity of hay for winter feeding they could raise on their irrigated ranches in the river and creek valleys. The Okanogan ranges will last for a number of years, but as the country is gradually settled up these grazing lands will eventually suffer the same fate as all other grazing lands in the State, unless some system can be devised for their protection.

The area of free range in the mountains is also rapidly decreasing. The creation of two large forest reserves in the Cascades—the Washington Forest Reserve in the northern part and the Mount Rainier Forest Reserve in the southern part—has greatly reduced the free mountain range. While, of course, stock is not entirely prohibited from these areas, the number allowed on them is far less than was accustomed to graze there before the reserves were created. This restriction has naturally resulted in a very crowded condition of the stock in the summer pastures outside of the reserves, and at the rate at which the grass was being taken a couple of years ago it looked as though these areas would soon be as badly devastated as the lower range lands. However, within the last three years the timber companies have been buying up large tracts, part of which they are leasing to cattlemen for five-year periods, while no stock is allowed on the remainder. At the same time, in the more accessible areas, where the grazing season is long enough to make it profitable to do so, the stockmen have been purchasing large tracts of this summer range. These purchases on the part of the timbermen and the stockmen living in the near vicinity have resulted in almost entirely shutting out nomadic stock from their summer range.

RANGE IMPROVEMENTS.

The purchasing of the range lands of the State is greatly simplifying the problem of range improvement. The instant that the stockman has fenced his land he is in a position to protect it from all outside interference, and can control the number of stock allowed on it. Instead of following the old system of grabbing all that he can before some one else gets it, he will try to use his grazing land so that it will yield him the highest results from year to year.

WINTER PASTURES.

In the true arid region, where sagebrush (*Artemisia tridentata*) is the prevailing vegetation, fencing and protecting the land from overgrazing during that season of the year when the native forage plants are going to seed will in all probability be the only satisfactory method of restoration. This will not be at all difficult, for, owing to the scarcity of water and to the too great heat, the cattle and sheep are taken to the higher altitudes during the summer months. In this way the native vegetation will have a chance to make a good growth and go to seed each season without interference from the stock. Through this method the pasture will not only yield a crop of seed on which future improvements will be based, but the plants which have been grazed to a point very near that of extermination will be given a chance to regain their former vigor.

At the present time nearly all the perennial grasses have been destroyed. There are, however, enough of these remaining (having been protected by growing in clumps of sagebrush where stock could not reach them) to furnish a crop of seed, if given a chance, although this crop may be very light for the first year or two. In addition to these there are numerous annual grasses and weeds that make excellent feed which, if given an opportunity, will in time become quite abundant. There are also numerous perennial shrubs, such as white sage (*Eurotia lanata*), bitter brush (*Purshia tridentata*), hop sage (*Grayia spinosa*), and greasewood (*Sarcobatus vermiculatus*)—each having its characteristic locality—which yield a considerable amount of browse, and which will furnish seed for new plants.

The only time of year when special care will need to be exercised in the grazing of these pastures will be in the spring months, when the young plants begin to grow. If the land be too heavily grazed at that period the young plants will be entirely killed out. This trouble can, however, be easily remedied by dividing the grazing area into two or three pastures, and by grazing off that portion of the land which is to be allowed to restore itself during the winter and excluding the stock during the time the young plants are getting a start. The next year another field can be given a like chance, and so on, alternately. In this manner it would be only a few years--probably not more than seven or eight—before the so-called desert areas would be restored to their original carrying capacity before overgrazing took place. Meantime the stockman would have full use of his land, and would be able gradually to increase the number of stock grazing on it, provided he judiciously confined the aggregate of his stock to the limit of the carrying capacity of his range.

As an example of this, the writer has on several occasions observed with interest an area a few miles west of Sunnyside. In the early part of 1900 this land belonged to the open range. It was fenced during that season, and has since that time been used to some extent as a pasture. While this field has not been handled in an ideal manner, nevertheless the native perennial grasses, such as sand-grass or needle grass (*Stipa comata*), Indian millet (*Eriocoma cuspidata*), and woolly wheat-grass (*Agropyron subvillosum*), have become considerably more abundant each season. By the season of 1904 these grasses had become so abundant that it seems fair to conclude that if given an opportunity they will in the course of another three or four years make a very good stand.

Another very strong proof of what can be done in the semiarid region is shown in that part of the open-range lands lying above the Washington Irrigation Company's canal, directly north of Prosser. Although fully as many sheep as ever graze on this land during the winter season, the range is actually improving. This is due to the fact that the range horses have become much less numerous, having been sold to settlers or shipped out of the State. In this way the vegetation has been given an opportunity to reseed itself, and it has also had a chance to make some growth during the summer while the sheep and cattle were in the mountains.

In the sandy, sagebrush area lying some 15 to 25 miles south of the Great Northern Railway, in Douglass County—commonly known as "the desert"—there are several thousand acres of range land where there is still excellent feed. This consists mainly of needle grass (*Stipa comata*), Indian millet (*Eriocoma cuspidata*), and sunflowers (*Balsamorrhiza careyana*), while bitter brush (*Purshia tridentata*) and various species of Eriogonum and Phlox furnish a large quantity of browse. The reason the vegetation in this area remains good while that about it has been very nearly destroyed is due to the great scarcity of water, which renders it almost inaccessible to stock during the hot weather. At the present time horses are the only kind of stock that can graze in this region during the summer months, and even they can only penetrate some 10 or 12 miles at the most, being compelled to go to water every day or two. By reason of this the vegetation has a chance to reach its full growth and to go to seed during the summer season. During the winter months, when stock can go for several days at a time without water, this vegetation is all eaten off, but this comes at a time of year when comparatively little damage is done.

SEMIARID LANDS.

The semiarid or true bunch-grass lands can also by judicious management on the part of the owners be brought back to their original state of productiveness. The best method for improving these areas will be to fence them and protect them from all nomadic stock, and give the native grasses a chance to restore themselves.

The two most important of the native grasses are bunch wheat-grass (*Agropyron spicatum*), which grows on the hillsides and plateau lands, and giant rye-grass (*Elymus condensatus*), which grows on the bottom lands and on the more or less alkaline situations.

At the present time there are large areas (see Pl. III, fig. 1) where all of the native grasses, except June grass (*Poa sandbergii*), have been destroyed. The latter—owing to the fact that it is not relished by stock after it begins to head out—is still quite abundant and furnishes a large amount of spring grazing. Wherever these plants are destroyed sagebrush (*Artemisia tridentata*) and rabbit brush or "yellow sagebrush" (*Chrysothamnus nauseosus*, *C. viscidiflorus*), and other weeds that are not relished by stock have taken their places.

There is considerable difference of opinion among the stockmen as to whether or not the native grasses, especially bunch-grass, will restore themselves if given an opportunity. Some claim that these grasses will come back if given a chance, while others maintain the contrary opinion. Both are in a measure correct. The truth of this matter depends largely upon how long these grasses have been too closely grazed. If they have been kept grazed down to a point where they have had no opportunity to go to seed for a number of years, and until the roots, unable to withstand the strain put upon them, have died out, they will, of course, not come back. If, on the other hand, as is for the most part true, the roots have not been absolutely killed out or there is still some seed left in the ground, these grasses will eventually restore themselves, although this process may be extremely slow.

During the seasons of 1901, 1902, and 1903 experiments were carried on in the Rattlesnake Mountains, where the annual precipitation is approximately 13 inches, to determine what grasses and forage plants would be of value for use in the restoration of the range. These experiments proved that bunch-grass could be successfully grown on cultivated ground. They also showed that alfalfa could be profitably raised in that locality and that hairy vetch (*Vicia villosa*) might prove of value in range improvement. In this work no forage plant was found that would give any better yield than the bunch wheat-grass or the other native grasses. Even if such a plant could be found it is doubtful whether it would stand the actual hardship that the bunch wheat-grass or giant rye-grass will endure, or would have the high feeding value of the two plants mentioned.

Where the range is in a very bad state of depletion, and where the native grasses have been nearly exterminated, it is believed that the process of restoration can be greatly hastened by gathering seed of bunch-grass and scattering it in those areas where it formerly grew. While experiments to prove this point have not been carried out, it is very probable that in favorable seasons reseeding would be very successful if the seed were harrowed in or, if more convenient, thoroughly stamped in by herding a bunch of sheep over the area seeded. Not only will reseeding hasten this process of restoration, but it will give the bunch wheat-grass a start over the weeds that are at the present time taking its place in those areas where overgrazing is going on. Experiments to determine this point will be made during 1905. The same thing can be done with the giant rye-grass. At the present time the seed of these grasses can not be purchased, but usually it would not be difficult to gather it. This can be done by heading the grasses with a sickle and putting the heads in a sack, or, if a large quantity is desired, there is no reason why the bunch-grass could not be gathered with a header and thrashed out with a flail. A thrashing machine could be used instead of a flail if the wind were shut off. The giant rye-grass could easily be gathered by using a self-binder.

In the foothills region lying between the semiarid grazing lands and the mountain meadows there are large areas of scab land (land where the soil is very thin and gravelly and full of stones), especially on the hilltops (see Pl. II, fig. 1). In these regions the grasses have been almost completely destroyed, and the prevailing vegetation now consists of scab-land sagebrush (*Artemisia rigida*), mountain sagebrush (*A. arbuscula*), bitter brush (*Purshia tridentata*), and various species of Eriogonum, all of which furnish considerable browse. Under proper management the grasses here will eventually restore themselves, but the process will take a long time, in some instances probably ten to fifteen years. The restoration may be hastened by scattering bunch wheat-grass seed, but it is, perhaps, a question whether the process of restoration will not cost more than the original value of the land.

MOUNTAIN GRAZING AREAS.

The mountain grazing areas, or summer pastures, are at the present time very important factors in the range problem of the State. With the large quantities of hay that can be raised in the irrigated valleys for winter feeding, the number of range stock that the State can support is—except in the Okanogan country, where the quantity of hay raised is limited—directly dependent upon the number of stock that these summer pastures will carry.

Fortunately, the restoration of the mountain grazing areas will not be at all difficult. Here the annual precipitation is ample to support an abundant vegetation, which, if given an opportunity, will soon grow up again. While in many of the mountain areas the vegetation has been badly cleaned out by sheep, the most serious damage has been caused by stock tramping on the land too early in the season, which has resulted in the ground becoming badly packed. In the true mountain meadows (see Pl. II, fig. 2), where mountain clover (*Trifolium longipes*), mountain timothy (*Phleum alpinum*), and various sedges and rushes comprise the vegetation, there is still an abundance of feed, but the carrying capacity of these places has been greatly reduced by the continual tramping of stock and consequent packing of the ground. On the hillsides surrounding these meadows, where the soil is much lighter, the herbage has in many places been killed. This, if protected and given an opportunity, will quickly return. The worst feature in this restoration process is that many weeds which have been brought in by the sheep, of absolutely no value for grazing purposes—not even the sheep will eat them—are given an equal chance with the good forage plants.

In many places, some of them covering large areas, the process of restoration can be very greatly hastened by reseeding. Not only can these areas be brought back to their original carrying capacity by reseeding, but it is the firm belief of the writer that in many instances their carrying capacity can actually be made much greater than ever (see Pl. I, figs. 1 and 2). This is especially true of the mountain meadows. In the majority of cases the reseeding can be done at a very small cost, varying from 75 cents to $2 per acre, depending on the kind of grass seed used and the number of pounds per acre. Even these figures can probably be lowered if the seed is bought in considerable quantity.

In the mountain meadows that are not too swampy, especially in those areas where mountain clover grows abundantly, timothy can be used to excellent advantage. For the outskirts of these meadows, where the soil is a little too dry for timothy to make its best growth, tall fescue (*Festuca elatior*), brome-grass (*Bromus inermis*), and probably orchard grass can be recommended. On the gravelly hillsides mountain brome-grass (*Bromus marginatus*), a native grass, can be grown to good advantage. So far as known, there is no seed of this latter grass on the market. However, if there should be sufficient demand for it, arrangements could be made for securing it.

The above conclusions have been reached after two years of experimentation and of study of the mountain conditions.

In the autumn of 1902 Messrs. W. H. Babcock and E. F. Benson offered the Office of Grass and Forage Plant Investigations the use of a section of land, which they agreed to fence, in their mountain pasture on the Wenatchee Mountains, about midway between Ellensburg and Wenatchee. This offer was gladly accepted, and experiments to determine what grasses could be used in the improvement of these mountain areas were immediately begun. The land selected is on top of the Wenatchee ridge, and is at an altitude of a little more than 5,000 feet. The conditions on this section are typical of true mountain range, varying from fertile mountain meadows and open parks to old timber burns and scab-land areas.

The following grasses and forage plants were seeded the same autumn: Timothy, Kentucky bluegrass (*Poa pratensis*), redtop, white clover, and mountain brome-grass (*Bromus marginatus*). These were seeded in plots of approximately 5 acres each. On half of each of these plots the seed was broadcasted without further preparation. On the remaining half the seed was harrowed in with a spring-toothed harrow. In addition to these, small plots of Canadian rye-grass (*Elymus canadensis*) and wild wheat (*Elymus triticoides*) were seeded.

In the spring of 1903 the first five plots were duplicated and the following grasses and forage plants were added: Brome-grass (*Bromus inermis*), perennial rye-grass (*Lolium perenne*), Italian rye-grass (*Lolium italicum*), orchard grass, Canadian bluegrass (*Poa compressa*), tall fescue (*Festuca elatior*), sheep's fescue (*Festuca ovina*), hard fescue (*Festuca duriuscula*), cheat (*Bromus secalinus*), alsike clover, and red clover. All of these, excepting orchard grass, Italian rye-grass, sheep's fescue, and mountain brome-grass, were duplicated in the fall.

In the autumn of 1904 some of these grasses, together with six different kinds of vetches and some native grasses, were seeded on plowed ground. Reports of these 1904 experiments will be published when completed.

In the above experiments the following grasses have given totally negative results, the seed failing to germinate: Canadian rye-grass, wild wheat (*Elymus triticoides*), Kentucky bluegrass, white clover, and hard fescue (*Festuca duriuscula*). In the following cases the seed has germinated fairly well, but the plants have not made satisfactory growth: Canadian bluegrass, perennial rye-grass, Italian rye-grass, red clover, and alsike clover. It may be that another year the alsike clover will do better. So far the writer has been unable to determine whether the failure of this plant has been due to lack of nitrogen bacteria or to unfavorable conditions in the soil. Another year's work will probably demonstrate the cause of the failure of this plant.

Redtop and cheat (*Bromus secalinus*) have both made a fair growth, but can hardly be recommended at this altitude (5,000 feet). Of the entire list of grasses tested, the following, in the order in which they are named, have proved themselves adapted to mountain range conditions: Timothy (see Pl. I, figs. 1 and 2), mountain brome-grass (*Bromus marginatus*), tall fescue, and brome-grass. It is probable that orchard grass will also prove of value in such areas.

While these experiments have demonstrated that the range can be greatly improved by reseeding, they have also shown that, if it is possible to do so, the seed should be harrowed in. On those areas where the soil is loose, or where pine-grass (*Calamagrostis suksdorfii*) grows, a spring-toothed harrow will be found the most satisfactory. On those areas where the sedges and mountain clover abound, far better results will be obtained, if the cost is not too great, by using a disk harrow. In many cases it is quite possible that a bunch of sheep would be fully as efficient, although this can not be recommended with assurance, as it has never been tried. The timothy seeded on the plots without harrowing, in the autumn of 1902, germinated fairly well, but the difference between the harrowed and unharrowed parts of the plot was very great—great enough, in fact, to well repay the cost of harrowing. The same thing held true on the plots of redtop and mountain brome-grass.

In the work of the spring of 1903 nearly all the seed not harrowed in failed to germinate, while wherever the seed was harrowed in a fair stand was obtained. This latter experiment, and a study of the soil conditions, would show it to be a waste of effort to seed in the spring without covering, as the top of the ground dries off before the seeds can get moisture enough to enable them to germinate and grow. Mr. Benson, one of the owners of the range, thinks that the experiments have shown conclusively that it is a waste of seed to sow it without harrowing. This is undoubtedly true of spring seeding, and probably also of fall seeding with many of the grasses. However, it is possible to sow timothy and mountain brome-grass and to secure a fair stand without covering, but, as stated above, the extra cost of harrowing will be well repaid.

The use of the harrow is also strongly urged for other reasons. It is very noticeable that wherever the harrow has been used the native grasses and forage plants have germinated much more profusely, and in small spots where there happened to be seed scattered from a few individual plants the stand has been greatly thickened. This is especially true of one of the forms of *Bromus marginatus*, which grows native on that section, of mountain needle grass (*Stipa occidentalis*), and of the wild pea (*Vicia americana*).

In this connection, fall seeding instead of spring seeding is recommended. The reason for this is that the snow usually comes early in the autumn and goes away late in the spring. As a consequence, the ground seldom freezes deep, and when the snow melts in the spring it has a tendency to bury the seed sown late in the fall. On the other hand, if the seed is sown in the spring the top of the ground becomes so dry within four or five days after the snow has disappeared that the seed will have no opportunity to germinate unless the season should prove to be an unusually rainy one.

PROTECTION OF PASTURES.

So far emphasis has been put on the fact that fencing is the main secret of range improvement. Yet fencing is absolutely of no value unless the stockman will treat his pasture with just as much care as he would his wheat field. Fencing is merely a means to an end.

Many of the stockmen, especially cattlemen, seem to think that when they have excluded the outside stock, sheep in particular, from their land, it will carry whatever stock they may have, and they are disappointed if it does not. While it is true that some kinds of stock do more damage to a given range than others, the injury is caused not so much by the kind as it is by the number of stock and the methods used in handling it. Just because the stockman has fenced his range and excluded all outside stock he must not lose sight of the fact that he has not in the least changed the carrying capacity of his range.

To illustrate this point, the writer, during the season of 1904, had an opportunity to study a number of pastures that had been newly fenced. One of these pastures, owned by a stock company, was purchased in the summer of 1903 and fenced during the spring of 1904. This pasture was in a region where there is a great deal of scab land, which meant that the carrying capacity was naturally very low, and in a locality where the vegetation had previously been nearly destroyed by numerous bands of sheep. The owners, having eliminated the sheep and all other stock, did not estimate its carrying capacity, but turned all of their cattle into the pasture without further attention. In the autumn, when they came to gather in their stock, they found that every bit of feed, including all the browse the cattle could get, was gone, and that the stock were in very poor shape, some of them being in a half-starved condition. These men by overgrazing their pasture lost heavily, as they will have to feed a great deal of hay to bring their cattle back to the condition they were in when turned into the pasture. Not only did they lose heavily on the cattle, but they also did the range a very serious injury, for, instead of supporting more stock another year, its carrying capacity has been greatly lessened.

Another range adjoining the one just mentioned has also suffered heavily from overstocking. In this case the owners, at the time they turned their cattle in, believed that their range would actually improve with what stock they had on it. However, they miscalculated, and not only will it take considerable hay to bring the majority of their stock back to good condition, but it will also be some time before the damage done to their range can be made good. While these two pastures were the only ones observed that were so overgrazed that the stock were really poorer when taken out than when put in, several other pastures were noticed in which the carrying capacity will be lower another year than it was during the past season, owing to the fact that the native vegetation has been too closely grazed.

The first step that the stockman should take after his pasture is fenced is to make a careful estimate of the number of stock it will carry, *being very sure not to overestimate*, which he is almost certain to do. In making this estimate he must not base it on the maximum number of stock, i. e., all the stock that the pasture will carry and bring through in good condition without reference to the condition in which the pasture is left at the end of the season, but an optimum number. An optimum number of stock is that number which the pasture will carry and bring through in good condition at the end of the season, and still be left in condition to carry the same stock another year, and so on indefinitely. This means that the stockman must make a careful study of his range, and be ready to revise his estimates whenever he sees that it is necessary to do so. By far the safest plan will be to pasture somewhat under the optimum number, and thus be prepared for a mistake in the estimate or for an unusually dry year. In case the range is badly deteriorated when the stockman first gets control, it will be absolutely necessary that it be pastured considerably under the optimum number if he wishes his range to improve. While this may perhaps be a severe strain on him for the first year or two, it is nevertheless the only solution. In many instances he may be able to take advantage of the outside range while his pastures are improving.

Plate III, figures 1 and 2, shows very plainly the difference between maximum and optimum grazing. The pasture shown in figure 1 is very badly depleted and very little vegetation remains except June grass (*Poa sandbergii*) and weeds. This pasture, instead of being given a chance to revive, has been grazed to its highest carrying capacity each year, with the result that it is gradually deteriorating. The pasture shown in figure 2 belongs to the neighboring range. Its owner, instead of trying to get all out of his range that he possibly can from year to year, has, by using an optimum number of stock, given it a chance to improve. At the present time the carrying capacity of his range is at least double that of the pasture shown in figure 1.

Mr. Joseph Burtt Davy, in his report on the stock ranges in California, where the same range conditions have been passed through as are going on in Washington, says:

> Success on one range, as compared with failure on an adjoining one, is not due to any difference in location or other range conditions, nor to any difference in the grasses or other plants composing the pasture; the natural conditions generally are, or have been, identical with those of adjacent and less productive ranges. The secret lies in good management, and good management primarily consists in carrying the optimum number of stock and allowing plenty of grass to go to seed—to go to waste, as the majority of stockmen would call it.
>
> Mr. J. H. Clarke and Colonel Harding, both successful stock ranchers on a large scale, are agreed in declaring that over thirty years of experience proves that this surplus grass, instead of being wasted, is equivalent to so much capital invested in the range, and is the cause of the prosperity of the few as

compared with the failure or poverty of the many. Such men do not stock nearly up to the maximum. Owning their own ranges, and therefore not having to pay exorbitant interest on the capital invested, they are content with the profits obtainable from the optimum number of stock. As a result of this, they not only maintain a uniform carrying capacity without deterioration, but gain in other ways. Their wool is always cleaner and commands a half cent a pound more than that of their neighbors, and both their mutton sheep and their lambs command a higher price. "We aim," writes Mr. Clarke, "to keep no more stock than the range will easily support. Better a superabundance of feed than a scarcity." [a]

ALTERNATION OF PASTURES.

In many parts of the State of Washington the ranges would be greatly benefited if the owner instead of having one large pasture would subdivide it into a number of small ones, so that once in three or four years each pasture would have a chance to rest and reseed itself. This would not mean that the owner would be deprived of the feed from that field, but simply that he would let the field lie idle for a couple of months during the time of going to seed, and use the dry feed later in the season. It would probably be necessary to protect this field from heavy grazing long enough in the following spring to give the young plants a chance to become so well established that the stock would not pull them up.

This method has been tried with very good success in Texas, and has been found to be of great value in range restoration. Mr. J. G. Smith, formerly of the Office of Grass and Forage Plant Investigations of the Department of Agriculture, who made a careful investigation of the stock ranges of that State, makes the following statement:

> A rest of two or three months during the growing season in early spring would enable the early grasses to ripen and shed their seeds, thus perpetuating the early species. After the seed had fallen, the cattle could be turned on the grass for two or three months and again transferred to a fresh pasture. In the same way autumn and winter pastures can be secured. Several stockmen who have employed this method on a large scale for a number of years say that their ranges are continually improving, in marked contrast to the deterioration that had occurred through bad treatment of neighboring properties where the old methods were practiced. It is also claimed that pasture land thus treated will carry more head of cattle through the year and bring them out in better condition than where the herd has access at all seasons of the year to all portions of the range. [b]

Later experiments to prove this point were carried on by the Office of Grass and Forage Plant Investigations at Abilene, Tex., and the results have shown conclusively that alternation of pastures is one of the important steps in the improvement of the ranges of that State.[a]

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[a] Bul. 12, Bureau of Plant Industry, U. S. Dept. of Agriculture, p. 43.

[b] Bul. 16, Division of Agrostology, U. S. Dept. of Agriculture, p. 22.

In eastern Washington some of the more successful stockmen use this method to the extent of dividing their holdings into winter and summer pastures. Undoubtedly much of their success, as compared with the failure of others, can be very largely attributed to that fact.

USING PASTURES BEFORE GROUND IS SETTLED IN THE SPRING.

One of the most serious damages to the range is caused by turning the stock upon it too early in the season. A great deal of the injury that has been done by sheep is due to this cause. Their owners, in order to get ahead of others, have pushed the sheep out on to the bunch-grass land while the ground was still soft and "punchy." In this manner the ground became badly packed and many young plants were destroyed almost before they had begun to grow, while much of the prevailing vegetation was greatly retarded in its growth by being nipped too early in the season. This same process was kept up as they followed the retreating snow up into the high mountains. Numerous instances have been observed where sheep have been run over the mountain ranges even before the frost was out of the ground.

When the stockman once gets his range under his control he should endeavor to avoid too early grazing. He will find that in the long run it will be better to hold the stock from this area until the ground has become settled and the vegetation has had a good start. If it is impossible to do this, he should endeavor to confine the damage to as small an area as possible.

IMPROVEMENT OF STOCK.

Not only should the stockman do all he can to improve his land, but he should strive equally hard to improve the quality of his stock. In the early days, when there was plenty of good range, it made comparatively little difference about the quality of stock, as even a poor-grade animal would yield a good profit. To-day, with the rapid fencing of the range, these conditions are changed. Now grass almost everywhere costs money. Land must for the greater part be owned or rented. The stockman can no longer afford to keep that type of stock that does not give him the best returns for the effort expended and that will best cover his range, whether it be cattle, sheep, or horses.

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[a] Bul. 13, Bureau of Plant Industry, U. S. Dept. of Agriculture, pp. 19 and 26.

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Sand-grass (*Stipa comata*), 14.
Sarcobatus vermiculatus (Greasewood), 14.
Scab-land sagebrush (*Artemisia rigida*), 17.
Sedges (*Carex* spp.), 17.
Sheep's fescue (*Festuca ovina*), 19.
Stipa comata (Needle grass or sand-grass), 14, 15.
Stipa occidentalis (Mountain needle grass), 20.
Sunflower (*Balsamorrhiza careyana*), 15.

Tall fescue (*Festuca elatior*), 18, 19.
Timothy (*Phleum pratense*), 18, 19, 20.
Trifolium hybridum (Alsike clover), 19.
  longipes (Mountain clover), 17, 19.
  pratense (Red clover), 19.
  repens (White clover) 18, 19.

Vetches, 19.
Vicia americana (Wild pea), 20.
  villosa (Hairy vetch), 16.

White clover (*Trifolium repens*), 18, 19.
  sage (*Eurotia lanata*), 14.
Wild pea (*Vicia americana*), 20.
  wheat (*Elymus triticoides*), 19.
Woolly wheat-grass (*Agropyron subvillosum*), 15.

Yellow sagebrush (*Chrysothamnus nauseosus* and *C. viscidiflorus*), 16.

PLATES.

DESCRIPTION OF PLATES.

PLATE I. *Frontispiece.* Range improvement by reseeding. Fig. 1.—Mountain meadow where timothy was seeded in the autumn of 1902. The prevailing vegetation in the foreground is mountain clover (*Trifolium longipes*), which makes very little growth. Fig. 2.—The same plot illustrated in figure 1 two years later, showing the stand of timothy secured.

PLATE II. Types of permanent range land not adapted to other uses. Fig. 1.—Typical scab land. Bunch wheat-grass grew abundantly in these areas before overgrazing took place. Fig. 2.—A mountain meadow. A typical place for seeding timothy. Tall fescue and brome-grass will grow to advantage along the timber edges.

PLATE III. Bunch wheat-grass pastures. Fig. 1.—Bunch wheat-grass pasture that has been continually overgrazed until nothing but June grass (*Poa sandbergii*) is left. Fig. 2.—A bunch wheat-grass pasture that has been properly handled. The photographs for figures 1 and 2 were taken on adjoining ranges.

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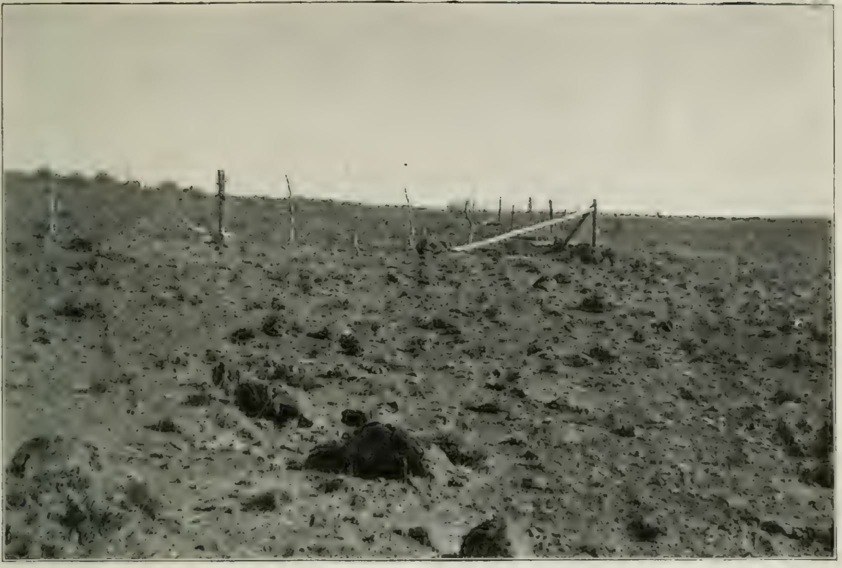

FIG. 1.—TYPICAL SCAB LAND.

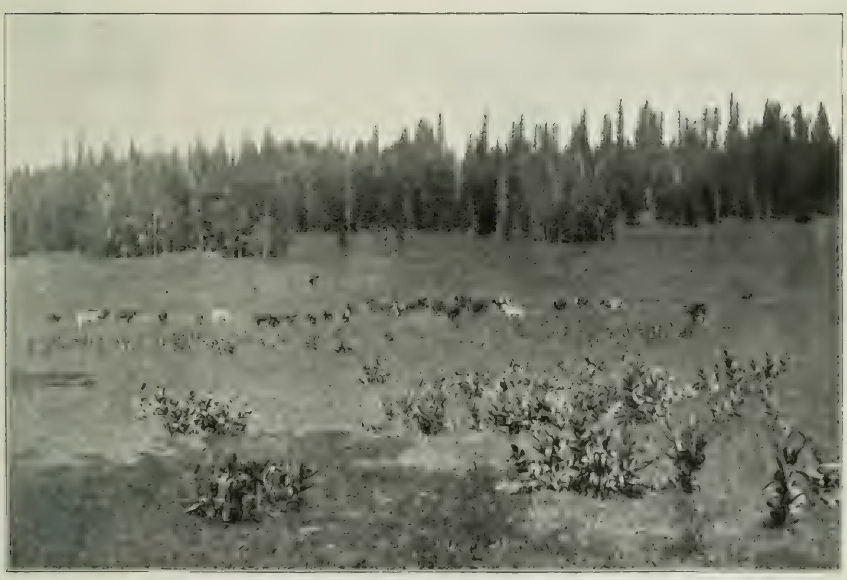

FIG. 2.—A MOUNTAIN MEADOW.

TYPES OF PERMANENT RANGE LAND NOT ADAPTED TO OTHER USES.

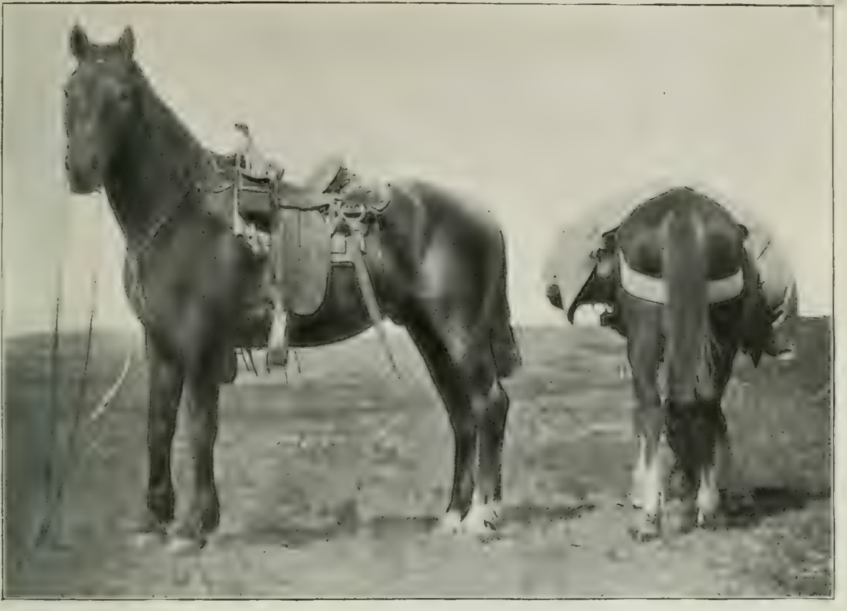

FIG. 1.—PASTURE THAT HAS BEEN OVERGRAZED UNTIL NOTHING BUT JUNE GRASS IS LEFT.

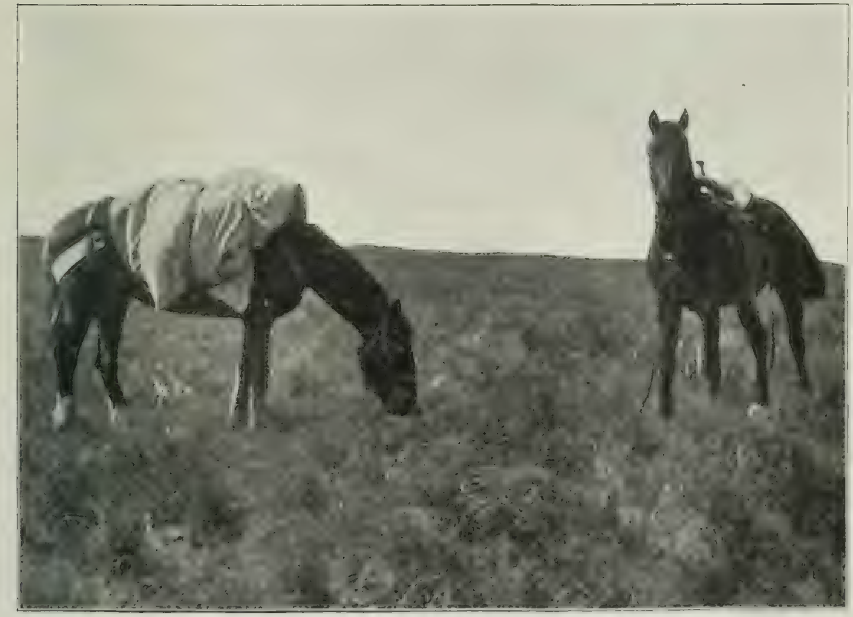

FIG. 2.—BUNCH WHEAT-GRASS PASTURE THAT HAS BEEN PROPERLY HANDLED.

BUNCH WHEAT-GRASS PASTURES.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 76.

B. T. GALLOWAY, *Chief of Bureau.*

COPPER AS AN ALGICIDE AND DISINFECTANT IN WATER SUPPLIES.

BY

GEORGE T. MOORE,
Physiologist and Algologist in Charge of the Laboratory of Plant Physiology,

AND

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VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS.

Issued April 3, 1905.

239387
13/1/30

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

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Pathologist and Physiologist, and Chief of Bureau.

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[a] Detailed to the Bureau of Forestry.
[b] Detailed to Seed and Plant Introduction and Distribution.
[c] Detailed to Botanical Investigations and Experiments.
[d] Detailed to Bureau of Chemistry.
[e] Detailed from Bureau of Chemistry.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., March 15, 1905.

Sir: I have the honor to transmit herewith a paper entitled "Copper as an Algicide and Disinfectant in Water Supplies," and to recommend that it be published as Bulletin No. 76 of the series of this Bureau.

This paper was prepared by George T. Moore, in charge of the Laboratory of Plant Physiology, and Karl F. Kellerman, Assistant in Physiology, in the Office of Vegetable Pathological and Physiological Investigations, and was submitted by the Pathologist and Physiologist with a view to publication. It is supplementary to Bulletin No. 64, "A Method of Destroying or Preventing the Growth of Algæ and Certain Pathogenic Bacteria in Water Supplies," and will be of interest and value to all who have to deal with the problem of preventing algal and bacterial contamination of water supplies.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

Investigations undertaken by this Office with a view to finding some cheap and practical method of preventing or removing algal and bacterial contaminations from water supplies have demonstrated the peculiar value of copper as an agent for this purpose. The possibilities in the use of this salt are briefly outlined in a previous bulletin (No. 64) entitled "A Method of Destroying or Preventing the Growth of Algæ and Certain Pathogenic Bacteria in Water Supplies."

During the summer of 1904 many lakes and reservoirs were treated under the direct supervision of representatives of the Laboratory of Plant Physiology, and it has become desirable to present the data gained in the season's experience, together with definite recommendations in regard to the methods of procedure, so that those having to deal with the question of contaminated water may do so to the best advantage.

With reference to the occasional objection offered to the use of copper as an algicide and disinfectant, it ought to be amply sufficient to state that a careful study of all the leading authorities on the subject fails to reveal any argument or evidence which can be adduced in opposition to the use of copper for this purpose. Authorities everywhere unite in defending the use of copper as a means of destroying polluting organisms in water, and agree that it can be used with impunity as advised by the authors.

ALBERT F. WOODS,
Pathologist and Physiologist.

OFFICE OF VEGETABLE PATHOLOGICAL
AND PHYSIOLOGICAL INVESTIGATIONS,
Washington, D. C., March 14, 1905.

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COPPER AS AN ALGICIDE AND DISINFECTANT IN WATER SUPPLIES.

INTRODUCTION.

At the time of publication of the results of the experimental use of copper sulphate as an algicide and disinfectant in polluted water,[a] definite recommendations concerning the proposed method of treatment were avoided. This was done both to check those who through ignorance or excess of zeal might be led to unnecessary or extravagant applications of the treatment and to gain the additional information of a season's experience by maintaining supervision over treated supplies. The work can no longer be considered in an experimental stage, however, and the present need is not an exposition or explanation of the method but a discussion of actual experience, which, by setting forth the conditions presented, the difficulties encountered, and the success attained, may serve as a guide to the water engineer and to those who find it necessary to use copper in dealing with contaminated supplies. An attempt is therefore made to arrange and correlate the results of laboratory work and practical applications of the method, with a view to facilitating the comprehension of the various ideas involved in the abundant results that the work has yielded. Moreover, it is apparent that the prejudice against using copper in drinking water is still great in many quarters, and some pains have been taken to ascertain whether there exist sufficient grounds for this hostility.

DIFFERENCE IN TOXICITY OF COPPER SULPHATE IN LABORATORY AND FIELD CONDITIONS.

The treating of various reservoirs has brought to light an interesting fact.

The concentration necessary to kill algæ in the laboratory is from five to twenty times as great as that necessary to destroy the same species in its natural habitat. The reason for this is difficult to demonstrate. It is not due to difference of light and temperature, nor to the greater proportion of the treated water to the mass of algæ so often found in reservoirs. The most probable explanation is that under normal conditions the rapid growth of the organism is favored, with a consequent maintenance of the highest degree of sensitiveness to adverse conditions. When algæ are brought into the laboratory, the change in environment and the injury from handling allows only the more resistant individuals to persist, and the forms developing from these are, therefore, harder to destroy than are those of the same species growing in nature.

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[a] Bulletin 64, Bureau of Plant Industry.

In view of this fact the quantities of copper sulphate which are required to destroy the different polluting forms are much less than those formerly considered necessary. Many of the concentrations in the following revised table have been obtained by actual use in reservoirs under natural conditions. The remainder have been determined by analogy, and only on theoretical grounds can they be presumed to be correct.

It will be seen that there is absolutely no possibility of correlating the effects of copper upon related forms with the idea of formulating a rule for general use. Even species of the same genus often show a greater variation in their susceptibility to copper than is found in widely separated genera, and the necessity of knowing the specific form causing the difficulty becomes more and more evident as experience with the effect of copper upon algæ is accumulated.

Number of parts of water to one part of copper sulphate in dilutions recommended for destroying different forms of algæ.

[Water of average hardness, and at a temperature of about 15° C. (59° F).][a]

Aphanizomenon	5,000,000	Microcystis	1,000,000
Anabaena circinalis	10,000,000	Navicula	15,000,000
Anabaena flos-aquae	10,000,000	Nitella	10,000,000
Asterionella	8,000,000	Oscillatoria	5,000,000
Beggiatoa	100,000	Palmella	500,000
Cladophora	1,000,000	Pandorina	100,000
Chlamydomonas	1,000,000	Peridinium	450,000
Clathrocystis	8,000,000	Raphidium	300,000
Closterium	6,000,000	Scenedesmus	1,000,000
Coelosphaerium	3,000,000	Spirogyra	25,000,000
Conferva bombycinum	3,000,000	Stigeoclonium	3,000,000
Crenothrix	1,000,000	Stephanodiscus	250,000
Desmidium	450,000	Synedra	600,000
Draparnaldia	3,000,000	Synura	3,000,000
Eudorina	100,000	Tabellaria	600,000
Euglena	1,500,000	Ulothrix	5,000,000
Fragilaria	4,000,000	Uroglena	20,000,000
Glenodinium	2,000,000	Volvox	4,000,000
Hydrodictyon	10,000,000	Zygnema	2,000,000
Mallomonas	500,000		

SALT WATER FORMS.

Cladophora	5,000,000	Ulva	5,000,000
Enteromorpha	10,000,000		

---

[a] See page 12.

EFFECT OF COPPER SULPHATE UPON FISH.

The effect of copper sulphate upon different species of fish demands more attention than was formerly supposed. The treating of a small trout pond in Massachusetts resulted disastrously to about 40 per cent of the 8-inch trout with which the pond was stocked, and emphasized the fact that all game fish are not equally resistant to the effect of copper. A series of investigations[a] has shown that the brook trout is more sensitive than any other fish yet tested. In some cases 1 part of copper sulphate to 7,000,000 parts of water is the maximum strength that can be endured by trout under 5 inches in length. Larger ones, as a rule, will endure but a slightly stronger solution, though the treatment of one reservoir was reported in which a solution of 1 to 1,000,000 was used without injury to trout or other fishes. Here, however, the immunity was probably due to the rapid precipitation of the copper by organic matter or alkalis[b] and not to the resistant condition of the fish. Reference to the reports of reservoirs treated, notably those of Butte, Mont.,[c] Cambridge, N. J.,[d] and Hanover, N. H.,[e] shows that fish are uninjured at concentrations ordinarily used and their presence is no obstacle to successful treatment.

Below are given the maximum amounts of copper sulphate which, judging from a very limited number of experiments, should be used in water containing fish of certain species. It is hoped that work planned in connection with the Bureau of Fisheries will make possible a fuller report upon this phase of the subject.

Number of parts of water to one part of copper sulphate in dilutions which will not injure fish of certain species.

Trout	7,000,000	Catfish	2,500,000
Goldfish	2,000,000	Suckers	3,000,000
Sunfish	750,000	Black bass	500,000
Perch	1,500,000	Carp	3,000,000

Experiments of the United States Commission of Fish and Fisheries[f] show that 1 part of copper sulphate to 582,000 parts of water will kill quinnat salmon in a few hours; this suggests that this fish is very sensitive, probably being killed at concentrations between those fatal for trout and those fatal for carp.

---

[a] At Coldspring Harbor, N. Y., through the courtesy of the Bureau of Fisheries and the New York Forest, Fish, and Game Commission.

[b] In water containing carbonates, if the amount of dissolved carbon dioxid is very low, the basic carbonate of copper formed may be considered insoluble; if, however, the water should contain a fair amount of carbon dioxid it would bring the copper carbonate at least partially into solution. In general, it will be safe to treat a lake with a concentration beyond that which the fish in it could endure in pure water, and the concentration may increase with the quantity of organic matter present.

[c] Page 15.

[d] Page 17.

[e] Page 20.

[f] Report of the Commission of Fish and Fisheries, Part XXVII, p. 118, 1901.

CONDITIONS DETERMINING THE PROPER QUANTITY OF COPPER SULPHATE FOR ERADICATING ALGÆ.

The importance of knowing the temperature of the contaminated water is second only to the necessity of knowing the organism present. With increase in temperature the toxicity of a given dilution increases, and vice versa. Assuming that 15° C. (59° F.) is the average temperature of reservoirs during the seasons when treatment is demanded, the quantity of copper should be increased or decreased approximately 2.5 per cent for each degree below or above 15° C. It is probable that the influence of temperature could be better expressed by geometrical than by arithmetical progression, but the accurate determination of this point can be made only after experiments have been recorded in various localities under different conditions for a number of years.

Similar scales should be arranged for the organic content and the temporary hardness of the water. With the limited data at hand it is impracticable to determine these figures, but an increase of 2 per cent in the quantity of copper for each part per 100,000 of organic matter and an increase of 0.5 to 5 per cent in the proportion of copper for each part per 100,000 of temporary hardness will possibly be found correct. The proper variation in the increase due to hardness will depend upon the amount of dissolved carbon dioxid; if very small, 5 per cent increase is desirable; if large, 0.5 per cent is sufficient.

APPEARANCE OF RESISTANT FORMS OF ALGÆ IN RESERVOIRS PREVIOUSLY TREATED.

Since adding copper to a reservoir destroys only the polluting organisms then present in the water, it is possible that other forms, the resting spores of which are buried in the mud, may develop after treatment and occasion a second pollution. There is thus the probability that some reservoirs will be cleansed of Anabaena or Oscillatoria or some such polluting species only to allow a subsequent development of forms more or less resistant to copper, such as some of the desmids. It is improbable that these organisms, or any of the algæ, in fact, could develop rapidly enough to be the cause of serious complaint and still remain resistant to such concentrations of copper as could be safely used. At the worst the presence of these forms is certainly to be preferred to that of organisms producing odor and taste, and fortunately experience has shown that the latter succumb so readily to the copper treatment that their destruction has offered no great difficulty.

ODOR AND TASTE DUE TO LARGE NUMBERS OF ALGÆ KILLED.

A certain proportion of the algæ killed by copper treatment floats to the surface and disintegrates there, but the greater part apparently sinks to the bottom, and it may sometimes be necessary to flush out this lower stratum of water and decaying organic matter. In case large masses accumulate upon the surface, as may occur in a reservoir very badly infested with Anabaena, it is desirable to skim off as much of this mass as possible. By this means the water can be rendered fit for use in the minimum length of time, although such procedure would be required only in a reservoir in which the polluting algæ had developed until the water was in very bad condition, and this should never be allowed to happen. The algologist of a water company should watch for the appearance of polluting forms, and advise treatment as soon as signs of increase are unmistakable.

The only undesirable effect of treating a water supply which is contaminated with an alga producing odor and taste is that during the first few days after treatment the odor and taste may increase. In a municipal supply in which the service mains are fed from the bottom of the reservoir this increase may be very marked and occasion additional complaint among the consumers. The trouble is, of course, caused by the simultaneous disintegration of large numbers of algæ and the consequent liberation of comparatively large quantities of the volatile oils to which the odor and taste are due.

REPORTS FROM VARIOUS CITIES AND TOWNS UPON THE EFFECT OF TREATMENT.

The copper method has been used throughout the year during different seasons and under varying conditions, and the work has fully demonstrated the value of this metal for destroying the contaminating algæ in reservoirs of drinking water, as well as in park lakes, fish ponds, and similar small bodies of water which must be kept in good condition. The first reservoir so treated was that of the Winchester Water Company, at Winchester, Ky. The organism polluting the water was *Anabaena circinalis*, and its destruction, as described in a previous publication,[a] seems to have been most thorough. But one treatment was made last year, and no complaint of the quality of the water has arisen since the summer of 1903. Experience only can determine how often a reservoir will need treatment, but the results at Winchester and with other large bodies of water in which none of the blue-green algæ, formerly so abundant, have appeared since the original treatment over a year ago, and this in spite of a season unusually favorable for their development, suggest that applications made at long intervals will suffice to prevent a recurrence of the contamination.

---

[a] Bulletin No. 64, Bureau of Plant Industry, p. 27.

In Massachusetts some abandoned reservoirs and ponds unfit for supplying water for drinking purposes have been treated, but as this work was done in cooperation with the State board of health, which has decided that further experiments are necessary to determine the final condition of the copper used in treating before advising the general use of this method, it seems best to defer publication of whatever results have been obtained until the board of health is in a position to make a definite statement.

Probably the most convenient form in which to group the year's results is an alphabetical list of some of the cities and towns in which such work has been done, and a résumé of the cases when necessary. It is impossible for various reasons to include in this list of all of the places where copper sulphate has been successfully used for the destruction of algæ.

BALTIMORE, MD.

Late in June Mr. Alfred M. Quick, engineer of the water department of Baltimore, reported some trouble due to algæ. The following extract from his letter shows the character of the pollution:

> For some time past this department has been in receipt of a great many complaints from consumers of the bad condition of the water. Ice makers were most interested, as it is necessary that water used in making ice should be perfectly clear. They complained that the bad condition generally occurred after long spells of rainy weather, and generally at the change of season—from spring to summer; also that it seemed to be practically impossible to eliminate discoloration. (June 25, 1904.)

Lakes Clifton and Montebello were visited on June 28 and were found to be badly infested with *Anabaena circinalis;* the organisms were unusually perfect spirals, and, estimated roughly, would count about 10,000 to 50,000 per cubic centimeter. On account of the pressure of municipal affairs treatment was not made until July 29, after which Mr. Quick wrote as follows:

> I have completed the experiment of treating the water in Lake Clifton with copper sulphate to eliminate the algæ, and I am glad to say that the result has been an unqualified success.
>
> Before the lake was treated it had a cloudy, greenish color. Immediately after treatment it had a steely, bluish color, and when the lake was turned into service again, one hundred and twenty hours after the application of the sulphate, it had a clear white color.
>
> Notwithstanding the small amount of sulphate used in proportion to the volume of water treated, all of the particular algæ which cause discoloration and odor, which I believe are the cyanophyceæ, were eliminated in forty-eight hours, and practically all of the various other kinds of algæ were eliminated in one hundred and twenty hours.
>
> As for any deleterious effect from the use of the sulphate, the city chemist reported to me that an analysis of 500 c.c. of the water one hundred and twenty hours after treatment showed no traces of copper. (August 9, 1904.)

Later Lake Montebello was treated, and reports of the results in both reservoirs were sent to this laboratory, together with a tabulated count[a] of the organisms before and after treatment. These sheets showed only a moderate reduction of algæ and a total number of organisms per cubic centimeter before treatment so small that it could never have been responsible for the complaints of the consumers, nor could these few organisms have produced the changes in color noted in Mr. Quick's letter. No Anabaena filaments were listed, though it is known that they were present in great abundance a month or so earlier when the examination was made by the Laboratory of Plant Physiology, and there is nothing in the conditions obtaining in the reservoirs before treatment that would explain their absence. It seems probable, therefore, that the samples examined by the city bacteriologist had been agitated sufficiently to break up the delicate Anabaena, or that on account of standing too long before examination this alga had disintegrated. The discrepancies between the tabular reports and the correspondence with this laboratory as they appear in the account of this work are undoubtedly due to this fact. The same explanation seems the most plausible one to apply to the fol-following letter from Mr. Quick, dated September 10, 1904, as the number and character of organisms mentioned by him were too small to produce any deleterious effect.

I am hardly in a position to state just what form of microscopical vegetable organism gives us the most trouble, but I have no doubt that the table will enable you to form some idea as to this. These organisms are not now giving us any trouble, but from the result of examinations made of samples of water taken a few days ago from Clifton and Montebello (which show the organisms now present to be about the same number or more than before treatment), it is likely that we shall have the same cause for complaint again in the near future.

BOND HILL, CINCINNATI, OHIO.

The following letter regarding the use of copper in a pond containing fish speaks for itself. The algæ, however, disappeared.

After weighing out a half ounce of copper sulphate, the quantity looked so small I added a little to it and dragged it through the water on a pole. Sunday morning (July 24) is when I treated it. Yesterday the water looked very bad, and the fish that have disappeared from sight all the summer were swimming on top and seemed in distress. (July 26, 1904.)

BUTTE, MONT.

The following extracts from letters and the report of Mr. Eugene Carroll, superintendent of the Butte Water Company, give details of the treatment made during the summer of 1904.

This company has a large reservoir containing about 180,000,000 gallons, that was completed in 1896. Notwithstanding the fact that we were particularly careful in cleaning the bottom and removing the soil, we have had continual trouble every year from the Anabaena.

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[a] Published in the Engineering News, 52 : 283.

The pest begins to show about the middle of June, and about the 1st of July the water is unfit for use on account of the odor and taste. It remains in a condition unfit for domestic use until about December, when the freezing weather purifies the water and we are able to use it during the winter. (June 3, 1904.)

It has been our custom for the past three years to cut this reservoir out entirely from our water supply from the time of the appearance of the taste and smell until the water purifies in the winter, so we can cut it out for any length of time necessary for the experiment.

Our reservoir is full of native trout, and while I do not care particularly about the fish, yet a solution strong enough to kill the fish might give us more trouble with the dead fish than we would have with the Anabaena.

As to the expense, that is a very small item to us, as we have spent nearly a million dollars in bringing in another water supply, largely on account of the spoiling of the water in our main reservoir. (June 14, 1904.)

(*Report after treatment.*) The Basin Creek Reservoir has two forks, one extending about three-fourths of a mile in a southerly direction and the other about one-half mile in a southwesterly direction. Distribution of the copper sulphate was started at 2 p. m. on July 7, using three boats. One boat distributed in the southern fork, another in the southwestern fork, and the third boat in the main body of the reservoir in front of the dam. The quantity used was 1 pound of copper sulphate to each million gallons of water, thus requiring 180 pounds of sulphate. One boat distributed 40 pounds in one hour in the short arm; the second boat distributed 60 pounds in one hour and ten minutes in the main body of the reservoir around the dam, and the third boat distributed 80 pounds in the long arm of the reservoir in one hour and fifty minutes. In each boat two men were used, one to row and one to hold the gunny sack containing the sulphate over the stern of the boat.

There was a heavy wind blowing downstream, which made it extremely difficult to row, but the boats were kept in continual motion from the time the copper sulphate was dropped into the water until it had entirely dissolved.

During the first ten minutes of the distribution of the sulphate nothing peculiar could be noticed in the water, but after fifteen minutes fine light-green threads began to float in it, growing steadily in number and extension until in about thirty-five minutes after starting there had formed a yellowish-green scum over the entire surface of the reservoir. The phenomenon was similar to the formation of a very flocculent precipitate.

In about two hours the scum assumed a dark-green color, the borders turning slightly brown. At that time a sample of the water was taken and carefully examined and small traces of copper were shown by the experiment. Samples of the scum were also examined and found to contain 11¼ per cent of metallic copper, showing that a large amount of the copper was taken up by the Anabaena and other organisms, and thereby removed from the water.

During the first twenty-four hours the water in the reservoir exhaled a more pronounced and disagreeable grassy odor than before treatment. Its color at the end of the first twenty-four hours was a decidedly dirty green, with comparatively very little scum floating on the surface, and upon testing 1,000 c. c. of the water for copper at this time, a very faint reaction was obtained. The sulphates in the water were slightly higher and the odor was considerably less.

At the end of the second and third days very slight changes were noticed in the color and taste of the top water, but it was greatly improved in taste, color, and smell below 20 feet in depth.

At the end of the fourth day a continued improvement was noticed in the taste, color, and odor, and at the end of the fifth day there was a very decided change for the better in color—the water assuming a natural color and only a slight odor and taste being noticeable on the surface. At 20 feet below the surface at the end of the fifth day, the water was tasteless and odorless, and of a bright natural color. Very slight changes for the better were noticed on the seventh, eighth, and ninth days, and on the tenth day the water apparently had assumed its normal condition.

Microscopical examinations of the water, however, during this period, as shown in the appended tables, revealed the fact that there were a few spores of the Anabaena left in the water and that the Asterionella had begun to increase again.

Owing to these conditions, it was deemed advisable to give the reservoir a second treatment with the copper sulphate, and on the morning of July 19, twelve days after the first treatment, a second treatment was given in exactly the same manner and with the same quantity as the first treatment.

After the second treatment, very little change was noticed in the water on the surface of the reservoir, and hardly any scum formed. Twenty-four hours after the second treatment, the water showed a very decided improvement in color, with absolutely no taste or odor. On the third day after the second treatment, as shown by the analyses in the tables, the water was in an absolutely normal condition and entirely free of the vegetable organisms which had given us so much trouble in the past.

During the process of these treatments, the reservoir was entirely cut out from the city supply and no flow through it was permitted, the overflow being closed and the water allowed to rise slowly. With the exception of occasionally opening the overflow to remove the scum which had blown down against the dam and an occasional opening of the blow-off pipe, there was no current running through the reservoir during the period.

On Sunday, July 24, the water in the reservoir being absolutely pure for the first time in ten years during the month of July, it was turned on to the city mains.

The cost of the treatment of the reservoir, exclusive of the superintendent and bacteriologist, who directed the operations, was as follows:

360 pounds copper sulphate, at 9½ cents per pound	$34.20
6 laborers, four hours each, at 30 cents per hour	7.30
Total cost	41.50

Equivalent to 23 cents per million gallons.

This expense would be cut down were another treatment made, as only one man to a boat is really necessary.

Late in the summer Asterionella again began to appear in considerable numbers. The increase, however, has not been sufficient to demand further treatment this year.

I will continue to keep a close record of the condition of the water in this reservoir, and think very likely it will be advisable to give it a treatment early next summer.

There is no taste or odor whatever to the water, and we have had no trouble with that supply since the treatment. (December 1, 1904.)

CAMBRIDGE, N. Y.

It was impossible to obtain a sample of the organisms causing the trouble at Cambridge, N. Y., but from the description it seems most probable that it was Anabaena. The following letter from Mr. C. T. Hawley, secretary and treasurer of the Cambridge Water Company, sufficiently explains the situation:

The village of Cambridge is supplied with water from two reservoirs, which were built in 1886. One, the "Lower" reservoir, is supplied from springs, and the other, or "Upper" reservoir, is supplied from a small stream and by water pumped from the "Lower" reservoir. In the "Lower" reservoir there has always been a considerable growth of algæ, but there has never been any taste or odor imparted to the water until last fall. Prior to that the algæ has appeared to "ripen," float to the surface, and blow ashore, where it would be raked up and removed. Last year it sank to the bottom, and soon after the "fishy" odor became very offensive. The reservoir was then emptied, cleaned thoroughly, and refilled. In a short time, however, the taste and odor again became noticeable, and there was more or less trouble until June 9 last, when, having procured one of the bulletins issued by the Department of Agriculture, we used the copper sulphate. The effect was evident in twenty minutes to a half an hour in a decided change in color and appearance of the algæ growth. In twenty-four hours the taste and odor had disappeared and the algæ looked dead, having lost its green color. In a few days the algæ had entirely disappeared, and there has been no trouble since, though there is a slight growth just beginning to show in detached patches within a few days. The reservoir contains about 1,250,000 gallons and we used 10 pounds of sulphate of copper. This did not affect the native trout which are in the reservoir. No water was pumped from the reservoir for several days after the sulphate was used, but the outlet gate was closed and the flow from the springs raised the level of the water in the reservoir and reduced the strength of the dose; nevertheless when the water in the reservoir was emptied into the channel which conveys the overflow to the Battenkill, it cleaned out a heavy growth of algæ from that channel for its full length, about half a mile. If the present growth continues, we shall try the sulphate again this fall, using, however, a less quantity of it, as it is evident from the cleaning of the channel that a lighter dose does the work.

As there was a slight growth in the "Upper" reservoir, we gave that a dose about the last of June, using 20 pounds of sulphate of copper for 4,000,000 of gallons of water. The same effects were noticed as in the "Lower" reservoir, and there has been no growth of algæ since.

The use of the copper sulphate has certainly been most successful in our case. Not only has the water company been saved the considerable cost of repeated cleaning of the reservoirs, but the residents of our village have been saved the annoyance of having at times to use a most unsatisfactory water supply. (September 22, 1904.)

ELMIRA, N. Y.

The following is an extract from an article[a] entitled "The Copper Sulphate Treatment for Algæ at Elmira, N. Y.," by James M. Caird, consulting engineer:

The reservoir was constructed during the year 1870, by building a dam across a natural site. At the time of construction the timber and surface soil were removed from the parts to be flooded. The reservoir has a drainage area of about 4½ square miles, covers 38 acres, and has a capacity, when full, of 113,000,000 gallons. The supply is derived from springs and a small stream called Hoffman Creek.

At various times the water in this reservoir has been a source of trouble owing to its strong "fishy" odor and taste, due to a growth of Anabaena and Asterionella. At times, before the construction of the filter plant, it was necessary on account of the odor and taste to drain and clean the reservoir, the last cleaning being done during the summer of 1889. The growth has been so abundant that even in the winter, when it was necessary at times to use this supply, lime had to be added before filtration in order to remove the "fishy" taste.

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[a] The Engineering News. **52:** 34.

The temperature of the water at the time of treatment was 64° F. In all 1,000 pounds of copper sulphate were used in treating the 90,000,000 gallons. This was equal to 1⅓ parts of copper sulphate per 1,000,000 parts of water, or 1⅓ pounds for every 120,048 gallons of water.

The reservoir was treated June 25, and none of the water was used until June 27, thirty-six hours after treatment. A sample of one liter, taken on June 27 and evaporated to 100 c. c., failed to give the copper reaction when tested with potassium ferro-cyanide.

The Anabaena disappeared thirty-six hours after treatment, while the Asterionella disappeared eighty-four hours after treatment. In looking over the preceding table it is seen that there was a reduction in bacteria of 86.7 per cent in thirty-six hours; 91.8 per cent in eighty-four hours, and 94.3 per cent in one hundred and eight hours.

Before treatment five samples of 1 c. c. each were examined for *B. coli communis.* Two gave positive results. Thirty-six hours after treatment this bacillus could not be found.

In operating the filters it was found that after the treatment the period between washings had been increased three hours, and the wash water was reduced from 2.3 to 1.9 per cent.

The effect of the copper-sulphate treatment on the different animal life was as follows: Numerous "pollywogs" killed, but no frogs; numerous small (less than 2 inches long) black bass and two large ones (8 inches long) killed; about ten large "bullheads" were killed, but no small ones; numerous small (less than 2 inches long) "sunfish" were killed, but no large ones.

The wind brought the dead fish to the corners of the reservoir, and it was very little trouble to remove them. No dead fish were seen twenty-four hours after completion of the treatment.

FIELDHOME, N. Y.

The following extracts from letters of Mr. C. DeP. Field, owner of the estate, summarize the results obtained at Fieldhome, N. Y.

The reservoir is filled by a spring that was for years our sole supply for water, and which was satisfactory. The reservoir is of concrete, about 4½ feet deep, surrounded by trees which do not exclude the sunlight. It has no top, and may derive some of its supply from the rain. The cattle have drunk the water from the overflow without apparent ill effects, but the coloration of the water is unfortunate, and apparently there are algæ in it. (July 8, 1904.)

After treatment.—Day by day we could see the end of a stick inserted in the reservoir, a little deeper. (July 23, 1904.)

The reservoir has cleared sufficiently for the bottom to be seen in places and the stones on the plank put in to walk down for bathing are all visible. (July 28, 1904.)

GLENCOVE, LONG ISLAND, N. Y.

A pond in the vicinity of Glencove, Long Island, was overgrown with small organisms, chiefly *Volvox globator* and *Phacus microcystis.* These are resistant organisms, especially the Phacus, but as is shown in the following extract from a letter from Mr. R. A. Shaw, the owner of the pond, the treatment seemed promising, though it was impossible to get definite results.

I duly carried out your instructions and added the further quantity of sulphate of copper to my pond. I think there has been some improvement, but am unable to tell how much, because the water, as a general rule, begins to clear as the temperature becomes cooler. Under such conditions it will probably be necessary to treat several times during the warm season. (September 28, 1904.)

GREENWICH, CONN.

During the latter part of July Prof. F. S. Hollis, of the Yale Medical School, acting under advice from the Laboratory of Plant Physiology of the Department of Agriculture, treated the two reservoirs supplying Greenwich, Conn.

The following is an extract from a letter received from Professor Hollis, dated August 11, 1904:

> Algæ, especially Anabaena, which were abundant in Putnam reservoir, were completely removed, and a large growth of filaments encased in jelly and attached to waterworks, which was probably a developing stage of some form, almost completely disappeared within a week after treatment. At the upper end of the reservoir there has appeared since the treatment a considerable growth of infusoria. Bacteria increased from ten to twenty times after treatment. In Rockwood reservoir at the dam the total organisms, 384, with Chlamydomonas 93, decreased in four days after treatment to 91 with Chlamydomonas 6. On August 9 organisms had increased to 194 with Chlamydomonas 53 and the complaint as to water is continued as all evidence of the sharp odor of Chlamydomonas is not removed by their method of mechanical filtration. Temperature of Rockwood, 23.6° C.; of Putnam 25° C.

On account of the slight increase of the pollution mentioned in the last sentence of Professor Hollis's letter, a second treatment was advised, the solution used to be of the same strength as the former one. Presumably this was satisfactorily effective, as there has been no further complaint.

HANOVER, N. H.

In the case of the water supply at Hanover, N. H., it was impossible to obtain samples of the organism before treatment was made, and it seems that any one of several species might have been responsible for the pollution, though for geographical reasons it seems probable that the form in question is Uroglena. The following extract from the Eighteenth Report of the board of health of the State of New Hampshire, volume 18 (1903–4), pages 159–161, shows the results obtained:

> On account of the gradual sloping of the banks of the reservoir and the presence of many fish, a 1 to 4,000,000 solution was used. * * * It was estimated that there were about 100,000,000 gallons of water in the reservoir at the time. The copper sulphate was weighed out into 25-pound lots. One lot was placed in a gunny sack, which was held open by an iron spreader, the sack fastened at the top, and then attached to the stern of a rowboat. The boat was rowed back and forth across the reservoir, commencing where the water was deepest and ending along the edges where the water was shallow. This process was repeated along lines 25 to 30 feet apart until the whole area had been covered. The copper dissolved very quickly, the water being warm, which necessitated rowing rapidly while the sack was full and slowing up as the copper in the sack diminished.
>
> Another small body of water was treated in the same way, except in this case a 1

to 1,000,000 solution was used. No bacteriological examination had been made previous to the application to this smaller body of water. The application was made to this water as an experiment in reference to the effect upon the fish.

This body of water was quite shallow at the edges and about 8 feet deep in the center. The application was made in both cases on the same day between 10 a. m. and 3 p. m. The day was very warm, no wind, and a heavy thunder shower took place just as the work was finished. (July 19, 1904.)

The edges of the reservoir were inspected next morning, and no dead fish were found, no odor was noticed, and many very small fish were seen swimming about.

On the edges of the smaller body of water 86 small dead fish were picked up, the largest of these measuring 1½ inches in length. The appearance of these dead fish was very striking. Their abdomens were very much distended and many of them had buried their heads in the mud, and in all cases their eyes looked "popped out" from their sockets. No fish were seen which seemed to be injured. Quantities of fish about 2 inches long, and from that size up to 1 foot long, were seen swimming about in the water apparently in a perfect state of health. Both bodies of water were inspected each morning for four days; no more dead fish were found, and nothing remarkable was seen. There was no perceptible change in the appearance of the water. Samples were taken from the reservoir and from taps in town and examined for micro-organisms, with the following results:

June, 1904, 1,800 micro-organisms, other than algæ, per cubic centimeter.

July 16, 1904, 2,600 micro-organisms, other than algæ, per cubic centimeter.

The above was tap water. Algæ not included in this table:

Date.	Reservoir.	Tap.	Date.	Reservoir.	Tap.
1904.	*Per c. c.*	*Per c. c.*	1904.	*Per c. c.*	*Per c. c.*
July 20	7	2,400	October	(a)	840
July 21	5	400	November	(a)	800
July 22	15	20	July 16		(b)
July 23	20	15	July 20	(c)	(b)
July 30	(a)	40	July 21	(c)	(d)
August	(a)	500	July 22	(c)	(c)
September	(a)	986	July 23	(c)	(c)

[a] No examination. [b] Large numbers. [c] None. [d] Few.

Last examination for algæ was in August, when only a few grew on media.

The first day after the application the taste and odor had perceptibly diminished, and on the second day had disappeared altogether. The color also practically disappeared, and only a slight color reaction could be detected by delicate color tests. Chemical examination showed no trace of copper in the reservoir water. A sample was not examined from the small pond. No one in town except those immediately concerned in the work knew that anything was being done, but in two days after the treatment two different persons remarked upon the improvement and within a week no less than 11 individuals spoke of it. It is not generally known at this time that anything has been done to the water. Up to date there has been no bad taste, no color, and no odor when cold. At times I think I can detect a very slight odor on close observation when the water is warm.

Conclusion.—That the odor and taste were due to microscopic organisms. The color to a great extent was also due to micro-organisms. That the application of copper sulphate in the strength of 1 part to 4,000,000 of water is sufficient to destroy these organisms without injury to fish. That 1 part of copper sulphate to 1,000,000 parts of water as found in the ordinary reservoirs and ponds will, in addition to destroying micro-organisms, destroy the small fish.

The probabilities are that if the water was of an equal depth in all parts of our reservoirs and ponds 1 part of copper sulphate to 1,000,000 parts of water would not kill the fish, but as the edges are shallow and the bottom irregular, it is impossible to get an equal distribution of the solution until after the smaller fish succumb. There can be no fixed general rule; each case must be treated as conditions require.

HANOVER, PA.

The three reservoirs of this system were badly infested with Anabaena. Treatment was made the latter part of August on the first reservoir and several days later upon the other two. The surface of the water cleared within a short time, but the lower layers containing the decaying algæ were improving but slowly.

The following extract from a letter from Mr. Charles R. Delaney, chemist of the Consumers' Water Company, shows the final results:

> The results of the last test show such great improvement that Mr. Brough has been advised to let the bottom water run off until the odor shows only faintly and then to turn the water into the mains. (September, 1904.)

IVORYDALE, OHIO.

The small reservoir of the Proctor & Gamble Company at Ivorydale, Ohio, was badly infested with algæ. The following is extracted from a letter dated September 22, 1904, from that firm:

> We are glad to be able to report the complete success of the treatment of our reservoir with copper sulphate.
>
> We treated the water as you directed, using approximately one part copper sulphate to a million of water. At this time there were several large floating masses of algæ, and the water had a peculiar odor and taste. We treated the water Saturday afternoon, August 13, and allowed it to remain practically quiescent for several days. Monday morning we found the masses had turned brown in color and frothy, but still floating in the large masses. These masses, however, subsequently disappeared, and since then there has been no sign of the growth except in an old skiff to which the treated water did not penetrate. Here the mass is still green.

JOHNSON CREEK, WIS.

The Geo. C. Mansfield Company reports as follows with reference to the use of copper in two ponds at Johnson Creek, Wis.:

> We used three applications of the solution recommended, and used same in each of our two ponds. The applications were made three days apart and as per your instructions. We had intended to make one more application, but cold weather came on and the ponds froze over; however, from close observation of the results from the three applications, we think it very beneficial. The green moss had about all disappeared or turned scorched or brown color, and evidently was destroyed. We believe late in the fall to be a splendid time to make these applications, as most of the fish are in deep water and do not come in contact with the solution. We did not discover that a single fish was destroyed. (December 5, 1904.)

MIDDLETOWN, N. Y.

The following article, entitled "The Copper Sulphate Treatment for Algæ at Middletown, N. Y.," by James M. Caird, appeared in the Engineering News for January 12, 1905, pages 33–34.

The city of Middletown, N. Y., obtains its water supply from three impounding reservoirs (Monhagen, Highland, and Shawangunk) which are located some distance from the city. The water is filtered before being delivered to the consumers. The filter plant has a capacity of 4,000,000 gallons per day, consists of 4 gravity and 4 pressure filters, each set of 2,000,000 gallons capacity per day.

The water from Monhagen reservoir is used in the lower parts of the city and is passed through the gravity filters, while the elevated section uses the water from Highland reservoir after passing through the pressure filters. The water from Shawangunk reservoir discharges into Monhagen reservoir.

In recent years during warm weather considerable trouble has been experienced by algae growths, not only by the odor which they produced but also by the rapid "clogging" of the filters. At times the filters would require washing at intervals of four to five hours.

From a sanitary standpoint the quality of these waters is good, the drainage area being owned or controlled by the water department.

Monhagen reservoir.—The Monhagen reservoir, which was constructed in 1867, was the first to be treated with the copper sulphate, the reason being that the greater part of the city's supply is obtained from this source. This reservoir has a drainage area of 300 acres, surface area of 68 acres, and a capacity of 296,000,000 gallons. When treated, this reservoir contained 250,000,000 gallons. The copper sulphate was applied at the rate of 1 part to 3,333,000 parts of water.

Portions of this reservoir were covered with a heavy growth of Potamegeton (pond weed). Three days after the treatment this weed began to come to the surface, and was raked off. Upon investigation it appeared to have rotted at the root. The conditions in this reservoir permitted a very uniform application of the copper sulphate. No fish were killed, although they were present in large numbers.

The examination of this water, before and after the treatment, revealed the following organisms:

	Before.	Fourteen days after.
Diatomaceae:		
Synedra	2	....
Nitzschia	4	1
Chlorophyceae:		
Ulothrix	6	....
Closterium	3	....
Cyanophyceae:		
Oscillaria	6	....
Anabaena	15	....
Schizomycetes:		
Leptothrix	2	....
Crenothrix	2	....
Miscellaneous:		
Pleureonema	1	....
Notholea	2	....
Total per c. c	43	1
Bacteria per c. c	120	150

The odor from this water before treatment was noticeable at a considerable distance from the reservoir.

Shawangunk reservoir.—This reservoir was constructed in 1902 and has a drainage area of 422½ acres, a surface area of 101 acres, and a capacity of 434,000,000 gallons. There is a large quantity of decaying wood in this reservoir, as the stumps were not removed before the land was flooded. No growth of Potamegeton was shown.

It was very difficult to treat this reservoir in places, owing to the stumps. In going around the stumps the copper sulphate was applied a little stronger than in other parts of the reservoir. The consequence was the death of a few fish.

The organisms found in the water before and after treatment were as follows:

	Before.	Ten days after.
Diatomaceae—Nitzschia	8	1
Chlorophyceae:		
Ulothrix	10	1
Protococcus	....	1
Cynanophyceae:		
Oscillaria	14	....
Anabaena	12	....
Schizomycetes—Leptothrix	9	2
Total per c. c	53	5
Bacteria per c. c	300	260

Highland reservoir.—This reservoir was completed in 1891, has a drainage area of 341 acres, a surface area of 110 acres, and a capacity of 560,000,000 gallons. When treated, the reservoir contained 495,000,000 gallons. The copper sulphate was applied at an average rate of 1 part to 2,292,000 parts of water.

There are a large number of "coves" around this reservoir, which necessitated a stronger treatment, resulting in the killing of a few fish. I should estimate the strength of the copper sulphate in these localities at about 1 part to 1,250,000 of water.

As in Monhagen, this reservoir contained a growth of Potamegeton, which broke off after treatment and came to the surface, where it was raked off.

The organisms found before and after treatment follow:

	Before.	Six days after.
Diatomaceae—Nitzschia	7	1
Chlorophyceae—Protococcus	34	3
Cyanophyceae—Oscillaria	5	....
Schizomycetes—Leptothrix	5	1
Rotifer:		
Microcodon	10	....
Notholca	1	....
R. vulgaris	1	....
Total per c. c	73	5
Bacteria per c. c	400	360

The temperature of these waters at the time of treatment was about 68° F. The greatest trouble with the waters commenced about the middle of August. The copper sulphate was applied the first part of September, since which time the waters have given no trouble.

The destruction of the algæ in waters which are to be filtered by the mechanical process results in a great saving in the cost of operation. That is, after treatment less coagulant is required to free the water from the suspended matter, the period between the washings of the beds is longer and there is a reduction in the percentage of wash water.

The freeing of the reservoirs of the growth of Potamegeton was also very desirable beecause after its death, which occurs during cold weather, it decomposes and imparts a very distinct yellowish-brown color to the water.

The beneficial results were noticeable twenty-four hours after the application of the copper sulphate to these waters. * * * The total amount of water treated was 1,095,000,000 gallons. The cost of this treatment was as follows:

Copper sulphate, freight and cartage	$186.06
Cartage of boats	5.00
Labor, eighty-three hours, at 15 cents per hour	12.45
Total	203.51

Exclusive of examinations and supervision, this was at the rate of 18½ cents per 1,000,000 gallons of water treated.

MILLERSBURG, PA.

Treatment in the case of the reservoir at Millersburg, Pa., was undertaken by the Millersburg Home Water Company and this laboratory has no record of the organism causing the trouble. The following extracts from reports of T. F. Bradenbaugh, president of the water company, show the condition of the reservoir:

July 31, 1904.—9 a. m., copper sulphate placed in the reservoir, 2 pounds per million; 7 p. m., slight change in the color of the water.

August 1.—7 a. m., color changed considerably; 7 p. m., water clearing.

August 2.—7 a. m., color changed to blue-green and much clearer; 7 p. m., water clearer, bottom of reservoir dimly seen.

August 4.—6 p. m., objects on bottom of the reservoir plainly seen. Small white particles seem to be suspended in the water; these are rapidly settling, leaving the water clear as crystal.

November 12.—After having sent you sample of water, and before receiving your letter dated August 16, the water in our reservoir became so bad both in color and odor that we gave it a second treatment, using the same quantity and method as in treatment No. 1.

The water again cleared and odor disappeared, but not to so marked a degree as after the first treatment. (Several fish died during this treatment.) The effect of treatment No. 2 lasted about three weeks, when the conditions again became so bad that we treated it a third time, with about the same results as No. 2.

After this treatment we changed our pumping system, so that instead of pumping into the reservoir we pumped direct into the pipe lines, allowing the surplus to back up into the reservoir. From that time we have had no trouble, but the water in the reservoir still retained its greenish color until cold weather came; now it is changing and is nearly as clear as crystal again.

It seems that deep-well water, if allowed to lie in a shallow basin or reservoir under a hot sun, will develop these troubles with great rapidity.

By tracing down the source of contamination and thoroughly sterilizing that, as well as treating the reservoir, there seems every probability that this polluting form could be eradicated.

MONCTON, NEW BRUNSWICK.

The report upon the conditions and effect of treatment at Moncton is of especial interest on account of being the only one dealing with an icebound reservoir. The following extracts from letters from Mr. J. Edington, city engineer, and from the Daily Times, of Moncton, show the method of treating and the results obtained:

Our trouble is almost entirely confined to the winter months, when the reservoir is frozen over. It varies more or less according to the length and severity of the winters, but the past two have been particularly bad.

In 1903 and 1904 the reservoir was frozen over on the 20th of November, and on the 17th of January the odor and taste commenced. This continued until the 7th of March, when the spring rains and freshets brought relief.

The conditions this winter are very much the same. Openings have been kept in the ice, but with zero weather they are not much good, as the ice forms as soon as holes are made.

The reservoir has a capacity of 200,000,000 gallons and is 30 feet deep at the gate house, and it is noticeable that the top layer of 5 feet is comparatively free from taste and odor, while at 10 or 15 feet the trouble is bad.

If the copper sulphate treatment has to be done in the winter, could it be effectively applied when the ice is from 2 to 3 feet thick? (February 13, 1905.)

The daily consumption of water is 1,250,000 gallons in twenty-four hours. How would it do to place, say, one-fourth of a pound in gate house every six hours, or a lesser quantity oftener, so that the proportion would be 1 pound per million gallons? Of course there is no current in gate house, as the water remains at same head as in reservoir. (February 24, 1905.)

The experiment was commenced at noon on the 8th instant by suspending two bags of copper sulphate, each containing 2 ounces, on a level with inlet pipes in gate house.

The daily consumption of water is estimated at 1,250,000 gallons, but the quantity of copper sulphate was based on 1,000,000 gallons, the idea being to apply 4 ounces every two hours, thus giving 1 pound per million gallons.

It was found that the crystals dissolved too quick, and the quantities were changed to 2 ounces every three hours.

A large opening, 100 feet by 40 feet, is cut in the ice adjacent to gate house and immediately over intake pipes. This has also been treated every second day by the application of 1 ounce forenoon and afternoon, this quantity being put in a small bag attached to a long pole and trailed up and down through the water until dissolved, the object in view being to get as even a distribution as possible of 1 pound of copper sulphate per million gallons every twenty-four hours. The result has been a great improvement in the water not only in the taste and odor, but in its color. (March 14, 1905.)

The experiment was tried several days ago, and immediately an improvement was noticeable in the water. Yesterday the improvement was so marked that it was a matter of comment among the citizens. The improvement, however, was attributed to the melting snow, but as a matter of fact there has been no new water from this source up to the present time. * * * Engineer Edington is satisfied that a solution of the trouble with the water in the winter season has been found. (The Daily Times, Moncton, New Brunswick, March 14, 1905.)

NEW YORK, N. Y.

The following extract is taken from a paper read before the American Chemical Society[a] by Mr. Daniel D. Jackson, chemist in charge of the Mount Prospect Laboratory in Brooklyn:

The department of water supply and the department of parks of New York City have both had waters treated by the author during the summer with decided success, and in each case only one treatment extending for a period of one hour was necessary.

NEWTOWN, PA.

The reservoir at Newtown, Pa., is a small one, with a summer temperature close to 60° F. The number of *Scenedesmus caudatus* per cubic centimeter was sufficient to give a decided green color to the water, and a scum or film would form during quiet weather. As the organism is a resistant one, two treatments were made about one week apart.

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[a] Science, **20**: 805. See also The Engineering Record, October 29, 1904.

Mr. T. J. Kenderdine, of the Newtown Water Company, gives an account of the work in the Intelligencer, from which the following is quoted:

The Newtown Artesian Water Company was put in operation sixteen years ago, and was a case of ground water pumped into an open basin. The water was analyzed as chemically pure, and in the absence of knowledge of alga the managers were surprised to find a discolorization in it the coming summer, with a taste as it increased that brought complaint from the consumers. To relieve this the water was let out, when a green sediment was found coating the bottom and sides of the basin. This was removed by a thorough flushing and scrubbing with stiff brooms, when it was thought the trouble was over. This was not the case, and for the past sixteen years there has been a repetition of this attempt to remedy the evil, which was found to be a vegetable growth in the water developed by the sun or to exposure in an open basin. The only way after it appeared in April was to empty the reservoir weekly, after running the water down to a depth of two and a half to three feet, and refill it; then, at the end of each month or six weeks, have a general scrubbing and brushing of the sedimented water to a prepared depression, where it was pumped or carried over the rim of the basin in buckets. The only other remedy for riddance of the pest was to roof over the whole surface, to erect a brick cistern in the center of sufficient size for household needs, and with an outlet for the main body of water in case of fire, the inlet from the pumping station coming up through the center, and roof that in, and thereby save the prohibitory expense of covering the whole reservoir, or to pump night and day into the street mains to give the consumers fresh water, and leave a stagnant pool in the basin, or throw away the work spent on erecting the basin and erect a standpipe. All these were thought of by those interested, but the cost and uncertainty of results deterred action, and the alga trouble seemed as if it would stretch out indefinitely into the future, with its cost of riddance and drain on the coal pile to replace the lost water from wells from 150 to 200 feet deep to a storage basin 60 feet above their surfaces. The remedy, however, without the expenses these would involve was not far off.

The second application was made September 24, when it was found a marked change had taken place for the better in the character of the water. The greenness was going and so was the fishy taste.

Nine days later an examination of the reservoir was made, when it was shown that the water was absolutely clear and that there was no need of further treatment. It is now three months since the water has been let out or the reservoir cleaned, and the effect of the small amount of copper used is marvelous. The water in the basin is as clear as a lake, and comes from the household faucet as if piped from a spring. The days of letting out alga-infected water and its replacement, as well as the monthly cleaning, which was looked for as surely as the new moon in the warmer seasons, are now of the past, and, as a matter of course, the hours for pumping lessened, as well as the drain on the coal pile, and, better than all, there was no longer any complaints coming from the consumers. In dollars and cents the cost of the new mode was not over $1, while the old way would have been $60 in the time since the last cleaning of the reservoir.

OBERLIN, OHIO.

George N. Carruthers, Springdale Farm, reports as follows:

You may recall my visit at your headquarters last spring, and your call at my farm to inspect my water-lily and lotus pond, and your recommendation for the destruction of algæ. Your remedy was entirely successful. (October 24, 1904.)

PASSAIC, N. J.

It is evident that the source of contamination at Passaic, N. J., has not been eradicated, and it seems that with the location and treatment of this source the water could be kept in good condition. The lake is a small one, owned by a land improvement company. Mr. Frank Hughes, agent for the company, writes:

> We have treated the lake twice this summer, and the last time we also applied the copper sulphate to the little pond above. There has been a slight return of the algæ, but so far it has not been enough to require another treatment. After the second treatment last summer there was no return of the algæ until about the middle of June this present summer. (September 19, 1904.)

PORT DEPOSIT, MD.

Early in May the water in the small reservoir supplying the Jacob Tome Institute at Port Deposit, Md., was in rather bad condition, due chiefly to the presence of Chlamydomonas. Treatment was made May 6, 1904, and on September 26 President A. W. Harris wrote as follows:

> The improvement in the taste and odor of the reservoir water was extremely marked. The water is now in a very satisfactory condition.

RHINEBECK, N. Y.

George N. Miller reported as follows on September 27, 1904, with reference to the success obtained in using copper in the lake on his estate at Rhinebeck, N. Y.:

> On August 3 I added 10 pounds of copper sulphate to my lake, and on August 5 there were hardly any signs of algæ left. About September 1 I treated again, as the algæ had reappeared, especially in the lower part of the lake. This time it was only fairly successful. It seemed to kill off about half of the algæ. A second application three days afterwards seemed to have but little effect. I should say that to kill completely needed a much stronger solution. The amount I used certainly did no harm to cattle, sheep, etc., and did not kill any fish.

The alga causing the trouble is a rather resistant filamentous form, but one which should be easily eradicated by treating as soon as the warm season begins to cause rapid development, and probably again late in the summer.

SCARBORO, N. Y.

The following is a report of the treatment of a pond on the estate of James Speyer.

> I dissolved 100 pounds of copper in the pond. Now there is not a bit of water-net to be seen. (July 25, 1904.)
>
> The quantity I roughly estimate at about one-half the quantity which you advised, but that solution did its work effectively and the algæ began to discolor in about twenty-four hours, and after thirty-six hours entirely disappeared, sinking to the bottom.

It is, however, only just for me to add that with the continuation of the hot weather the pond developed a rather disagreeable odor, and I also found several dead eels in the pond. Whether this odor is due to some fish which died on account of the copper sulphate or to the decaying of the plants which had sunk to the bottom I cannot tell, but in former years when the water supply was about the same as this year I did not notice the smell. (September 20, 1904.)

If the alga was allowed to develop until it was forming large masses it is to be expected that during its decay, subsequent to treatment, it would give off a very decidedly disagreeable odor.

SPRINGFIELD, ILL.

Arthur Hay, secretary-engineer of the Pleasure Driveway and Park District, of Springfield, Ill., wrote, under date of September 21, 1904, regarding the use of copper in a park lake, as follows:

The custodian reports that he has used 2 pounds of copper sulphate in a pond containing about 2,000,000 gallons of water thickly planted with water lilies and stocked with fish. The surface of the water was covered with a "brownish scum" [probably Spirogyra]. A few hours after the application of the sulphate the scum disintegrated into a curdy precipitate which remained entangled about the stems of the water lilies.

After waiting several days for this to disappear, and observing no change, he drew off the water, and after cleaning the pond refilled it with fresh water. He has not noticed any growth of the scum since. Neither the water lilies nor the fish were affected by the use of the sulphate. In another pond, with no water lilies, but bordered with cat-tails and aquatic grasses, there was no scum, but a heavy growth of a "stringy green moss." He applied copper sulphate here in the strength at first of 1 pound to 1,000,000 gallons of water, and later considerably stronger, but noticed no effect either on the moss or the cat-tails.

WALTHAM, MASS.

Bertram Brewer, city engineer, reported trouble due to algæ in the watering tubs in his pasture. Mr. Brewer wrote as follows on September 24, 1904:

Soon after I received your directions I filled the tubs with copper sulphate solution and let it stand in one tub forty-eight hours, in the other about a week. The result was that I have not had to repeat the dose oftener than once in three weeks. I found that a careful washing in the copper solution also prevented the growth of mosquitoes in my tubs, and that made it doubly desirable.

This is of interest on account of again bringing up the matter of the destruction of mosquito larvæ in pure water by copper sulphate.

WATER MILL, LONG ISLAND, N. Y.

The following letter, dated December 28, 1904, from Dr. Thomas T. Gaunt, New York City, is self-explanatory:

My place in the country is located at Water Mill, in the township of Southampton, in Long Island. I purchased it in April, 1902, and was largely influenced in selecting this piece of land by the beauty of a pond which bounds it on the east. This little body of water covers about 2 acres, is fed by numerous springs, and discharges into Mecox Bay, the southern boundary of the land. When I bought the place the pond was filled with clear water. About the middle of the following June algæ began to show, and in August the surface was almost entirely covered by the growth. The odor was offensive, and myriads of small insects hovered over the masses of algæ much of the time. I consulted two engineers interested in the storage of water, and they told me nothing could be done. The condition was so objectionable that I planned to plant a thick hedge of willows along the bank to shut off the view of the pond from the house. * * * I examined the pond on June 15 and found large masses of algæ covering an area several hundred feet in length and from 20 to 40 feet in width. No microscopical examination was made of the growth, but I was informed that it seemed to be largely composed of filaments of Spirogyra and other Conferveæ. On June 18 the treatment was begun. * * * In one week the growth had sunk and the pond was filled with clear water. I examined the pond on September 15 and found it still clear. From time to time during the summer small masses of algæ appeared along the banks, but they were only apparent on close inspection.

The use of the sulphate of copper converted an offensive insect-breeding pond into a body of beautifully clear water. The pond was full of fish, but the copper did not seem to harm them.

WELLSBORO, PA.

Anton Hardt, Wellsboro Water Company, wrote on August 16, 1904:

May 26 I distributed 15 pounds of sulphate of copper as directed by you. The algæ turned brown in three days and disappeared entirely inside of two weeks. There is no perceptible odor from the water at present.

WINCHESTER, KY.

William Wheeler, consulting engineer, Boston, Mass., wrote on September 14, 1904, as follows:

Among the many sources of water supply with which I have had relations as engineer and manager, under both municipal and private ownership, none has approached that for Winchester, Ky., in the intensity of the development of algæ therein or in offensiveness of the results arising therefrom.

The works were constructed in 1890, the source of supply being the impounded waters of a creek in the Blue Grass region, in which the flow varies from a violent torrent in times of heaviest rainfall to sometimes no appreciable flow whatever during one to three or four months of the driest summers.

The odor first appeared in a noticeable degree during the hot summer months two or three years after the works were constructed, and gradually increased from year to year—mitigated to some extent by means of filtration and aeration, yet nevertheless attaining to such a degree of offensiveness two years ago as to make its use for any purpose almost intolerable.

In April, 1903, I applied to Mr. Albert F. Woods, Pathologist and Physiologist of the Bureau of Plant Industry, to enlist the services of Doctor Moore in treating the Winchester reservoir by the copper sulphate process, and the results have been briefly set out in Bulletin No. 24 of the Bureau.

The treatment has once been renewed this season, and the water has thereby been kept entirely inoffensive to the senses of taste, smell, and sight, and made satisfactory to the owners of the works and the community which they serve.

The economic value of the treatment appears to be measured by what it would have cost to procure and maintain an entirely new and independent supply, the only practical source of which is the Kentucky River, at a distance of nearly 10 miles from the town and over 500 feet below it in elevation. The cost of installing and operating the additional works that would be required would be about twice as great as the cost of building and operating the present supply w6rks.

Charles F. Attersall, superintendent of the Wincnester waterworks, under date of October 8, 1904, said:

> The treatment of the reservoir was made on July 19, 1904, with a solution of 1 to 4,000,000 copper sulphate. The treatment was considered necessary owing to the appearance of Anabaena and a perceptible increase in odor. The solution was distributed through the reservoir in practically the same way as applied last year. The result of this treatment has been entirely satisfactory, and we have had no occasion to repeat it. The water has been in excellent condition all the year, with the exception of a very slight odor at the time the solution was applied. We have had no complaints from the consumers, which is the first time since the completion of the plant in 1891.

WINNEBAGO CITY, MINN.

The use of copper in this instance was for the purpose of removing the odor caused by the decay of Lemna and sedge that grew and decayed rapidly in the cooling pond of the Winnebago Flour Mills Company The amount applied was far in excess of what would be practicable if fish were present, and illustrates merely an incidental use of copper sulphate. S. W. Tredway, of the above company, wrote on September 17, 1904, as follows:

> We have applied sulphate of copper twice, putting same in a bag at a time when our pond was still and dragging it all around. We used 3 pounds of copper with each treatment. We have not been running hot water into the pond for some three or four weeks because of the fact that our condenser gave out, and we are now installing a new one, and consequently there has been no current through the pond during all this time.
>
> The copper has completely removed the odor arising from the pond, and there is no question but that the growth has been checked, and from appearances we should think that the weeds are commencing to die off. We probably will not be in a position to say definitely just what the results are before next spring. We are going to make an effort in the early spring to prevent a new growth entirely.

NECESSITY FOR DETERMINING THE POLLUTING ORGANISM.

Before the quantity of copper required in a particular reservoir can possibly be determined it is absolutely necessary to ascertain the exact character of the organism causing the trouble. This makes a microscopical examination of the first importance. Also, the earlier in its development the presence of the polluting form is revealed, the more effective will be the treatment. If examinations are made at short intervals throughout the year, the first appearance of the troublesome algæ can be noted, and by treating promptly at the first sign of their decided increase it is possible to destroy them before the consumer is caused any annoyance. This makes a considerable difference in the expense of treatment also, as it may require fifteen to twenty times as much copper to clean a reservoir after the bad taste and odor are evident as it would if the application had been made before the organism had established itself.

In all cases the use of copper is advocated as a preventive rather than as a cure, and the treatment can not be intelligently applied unless the microscopical examinations are thorough and frequent at the time of year the trouble is to be expected.

TROUBLESOME FORMS AND THEIR IDENTIFICATION.

The bad odors and tastes due to the presence of algæ may be due either to a definite secretion from the plant or to its decomposition. In most water supplies the difficulty is first evident before the algæ have begun to die, and, although the objectionable conditions may be augmented by subsequent decay, there are comparatively few alga-infested reservoirs in which the disagreeable effect is not originally produced by the living algæ. The effects directly produced by these plants have been so variously described that it is difficult to arrange any classification which will enable one to identify the organism by the odor or taste produced. In general, however, it may be said that the diatoms cause what has been termed an "aromatic" odor, although if in great quantity it is apt to be nauseating and fishy. Uroglena, which in this country usually appears during the winter months, is the form causing the most characteristic fishy taste and odor. Volvox is reported to have a similar effect. There are also certain forms closely related to both Uroglena and Volvox which at times may produce a flavor suggestive of fish.

During the summer by far the greatest difficulty in water supplies infested with algæ is due to the blue-greens, or Schizophyceae. The odor first noticeable has been described as grassy or moldy, but this usually changes as decay sets in to a pronounced "pig-pen" odor, which can frequently be detected for a considerable distance from the reservoir. Many of the larger grass-green algæ, such as Cladophora, Conferva, Spirogyra, Hydrodictyon, etc., cause trouble by being present in such quantities as to produce a distinct vegetable odor when they begin to disintegrate.

As many of the algæ occurring in water supplies are very minute, it is often necessary to resort to special methods to collect samples for identification. In some instances it is sufficient merely to allow a jar of the water in question to remain undisturbed for a few hours, when the algæ will have settled to the bottom, and it will be possible with the aid of a pipette or a small glass tube to remove a sample of this deposit to the glass slide for examination. If the organisms are motile, or if it is desired to estimate their number per cubic centimeter, the method described as the Sedgwick-Rafter method is the best for this purpose. The numerous requests for a means of determining quantitatively the algæ in water warrants the following extensive quotation:

THE SEDGWICK-RAFTER METHOD OF QUANTITATIVE DETERMINATION.[a]

The Sedgwick-Rafter method consists of the following processes: The filtration of a measured quantity of the sample through a layer of sand upon which the organisms are detained, the separation of the organisms from the sand by washing with a small measured quantity of filtered or distilled water and by decanting, the microscopical examination of a portion of the decanted fluid, the enumeration of the organisms found therein, and the calculation from this of the number of organisms in the sample of water examined. The essential parts of the apparatus are the filter, the decantation tubes, the cell, and the microscope with an ocular micrometer.

The filter.—The sand may be supported upon a plug of rolled wire gauze at the bottom of an ordinary glass funnel 7 or 8 inches in diameter, but the cylindrical funnel * * * is preferable. The inside diameter of this funnel at the top is 2 inches, the distance from the top to the beginning of the slope is 9 inches, the length of the slope is about 3 inches, the length of the tube of small bore is 2½ inches, and its inside diameter is one-half inch. The capacity of the funnel is 500 c. c. The support for the sand consists of a perforated rubber stopper pressed tightly into the stem of the funnel and capped with a circle of fine silk bolting cloth. The circles of bolting cloth may be cut out with a wad cutter. Their diameter should be a little less than that of the small end of the rubber stopper. When moist, the cloth readily adheres to the stopper. The sand resting upon the platform thus prepared should have a depth of at least three-fourths of an inch. The quality of the sand is important. Ordinary sand is unsatisfactory unless very thoroughly washed. Pure ground quartz is preferable. Its whiteness is a decided advantage. The necessary degree of fineness of the sand depends somewhat upon the character of the water to be filtered. A sand which will pass through a sieve having 60 meshes to an inch, but which will be retained by a sieve having 120 meshes, will be found satisfactory for most samples. Such a sand is described as a 60–120 sand. When very minute organisms are present a finer sand must be used, say, a 60–140 sand. The sand used for many years by the author had the following composition:

Size of sand grains.	Percentage by weight.
40– 60	20
60– 80	20
80–100	38
100–120	18
120–140	4
....	100

The sample to be filtered may be measured in a graduated cylinder or flask, or the filter funnel itself may be graduated. The graduated filter funnel is especially useful for field work, as it saves the necessity of carrying an additional graduate. The quantity of water that should be filtered depends upon the number of organisms and the amount of amorphous matter present. An inspection of the sample will enable one to judge the proper amount. Ordinarily 1,000 c. c. for a ground water and 500 c. c. for a surface water will be found satisfactory. In some cases 250 c. c. or even 100 c. c. of a surface water will be found more convenient. When the water is poured into the funnel, care should be taken not to disturb the sand more than is necessary, otherwise organisms are liable to be forced through the filter. The best plan is to make the sand compact by pouring in enough distilled water to just about fill the neck of the funnel and to pour in the measured sample before the sand has become uncovered. The filtration ordinarily takes place in about half an hour, but occasionally a sample is so rich in organisms and amorphous matter that the filter becomes clogged. It then becomes necessary to agitate the sand with a glass rod or to apply a suction to hasten the filtration. If the filters are located near running water an aspirator may be attached to the faucet and connected with the filter by a rubber tube having a glass connection that fits the bore of the rubber stopper. The use of the aspirator enables the filtration to be made in a few minutes, and not only effects a saving in time, but reduces the error caused by the organisms settling on the sloping surface of the funnel.

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[a] The Microscopy of Drinking Water, by G. C. Whipple, New York, 1899, p. 15.

Concentration.—As a result of the filtration the organisms and whatever other suspended matter the sample contained will have been collected on the sand. When all the water has passed through and before the sand has become dry the rubber stopper is removed and the sand with its accumulated organisms is washed down into a wide test tube by a measured quantity of filtered or distilled water delivered from a pipette or an automatic burette. The amount of water used for washing depends upon the number of organisms collected on the sand. If 500 c. c. of the sample are filtered it is usually best to wash the sand with 5 c. c., thus concentrating the organisms one hundred times. The amount of water filtered divided by the amount of water used in washing the sand gives the "degree of concentration." The degree of concentration may vary from 10 to 500, according to the contents of the sample. Ordinarily it should be 50 or 100.

By shaking the test tube the organisms will become detached from the sand grains. If this is followed by a rapid decantation into a second test tube most of the organisms, being lighter than the sand, will pass over with the decanted fluid, while the sand is left upon the walls of the first tube. To insure accuracy the sand should be washed a second time and the two decanted portions mixed together. If, for example, it is desired to concentrate a sample from 500 c. c. to 10 c. c., the sand should be washed twice with 5 c. c. and the two portions poured together. This will give a more accurate result than a single washing with 10 c. c.

It is necessary to allow for the volume of the sand and to use a definite amount of sand at each filtration. The 60–120 sand holds about 50 per cent of water, and ordinarily about 2 c. c. of the sand are used; hence an allowance of 1 c. c. must be made for the water held in the sand.

The cell.—The cell into which a measured portion of the concentrated fluid is placed for examination is made by cementing a rectangular brass rim to an ordinary glass slip. The internal dimensions of the cell are: Length, 50 mm.; width, 20 mm., and depth, 1 mm. It therefore has an area of 1,000 sq. mm. and a capacity of 1 c. c. A thick cover glass (No. 3) having dimensions equal to those of the outside of the brass rim (55 mm. by 25 mm.) forms a roof to the cell. The concentrated organisms in the decantation tube are distributed uniformly through the fluid by blowing into it through a pipette, and 1 cubic centimeter of the fluid is then transferred to the cell in such a manner as to distribute the organisms evenly over the entire area. This may be done by laying the cover glass diagonally over the cell so that an opening is left at either end, and flowing the water in at one end while the air escapes at the other.

The microscope.—An expensive microscope is not needed for the numerical estimation of the common microscopic organisms found in water. A simple, compact stand with a one-half inch objective and a 1-inch ocular is sufficient. For studying the organisms in detail and for general laboratory use in the study of water a large stand, with substage condenser, iris diaphragm, mechanical stage, etc., should be provided. The list of objectives should include a 2-inch, a one-half inch, a one-fourth or one-sixth inch, and a one-twelfth inch homogeneous immersion, or their equivalents, and there should be several oculars magnifying from four to twelve times.

The ocular micrometer consists of a square ruled upon a thin glass disk, which is placed upon the diaphragm of the ocular. The square is of such a size that with a certain combination of objective and ocular and with a certain tube length of the microscope, the area covered by it on the stage is just 1 square millimeter. For convenience it should be subdivided, as shown in fig. 6. The size of the largest square is 1 square millimeter. The size of the smallest square is one standard unit. The standard unit is represented by the area of a square 20 microns on a side—i. e., by 400 square microns. With a one-half-inch objective and a No. 3 ocular the square ruled for the ocular micrometer should be 7 mm. on a side. Before using the micrometer the proper tube length must be ascertained by comparison with a stage micrometer.

Enumeration.—The cell, filled with the concentrated fluid, is placed upon the stage of the microscope and the organisms included within the area of the ruled square are counted. It is then moved so that another portion of the cell comes into the field of view and another square is counted. This is continued until a sufficient number of representative squares have been examined. It is obviously impracticable to count all of the 1,000 squares which compose the area of the cell. It is usually sufficient to count ten or twenty squares, but a larger number ought to be scrutinized. In counting the organisms it should be remembered that some are heavy and sink to the bottom, while others are light and rise to the top. The observer should make a practice of changing the focus of the microscope so that both the upper and lower portions of each square may be examined.

From the number of organisms found in the ten and twenty squares it is an easy matter to calculate the number originally present in 1 cubic centimeter of the sample. If t represents the number of organisms found in 20 squares, $\frac{t}{20}$ will represent the number found in one square, and 50 t $(=\frac{t}{20}\times1000)$ will represent the number in the entire cell, or in 1 cubic centimeter of the concentrated fluid. This divided by the degree of concentration will give the number of organisms in 1 c. c. of the sample.

KEY FOR IDENTIFYING ALGÆ.

The following short key is given as an aid to those who have not access to the voluminous and scattered literature on algæ, in the hope that by this means forms which would otherwise remain unidentified may be recognized and treatment made to the best advantage.

CONJUGATAE.

Grass or yellow green algæ whose cells always divide in the same direction forming single cells or united into unbranched threads or filaments; no swarm spores. Produces zygospores, and occasionally akinetes and aplanospores.

Cell almost divided into two symmetrical halves by a constriction or thinning of the cell contents; almost always with double-layered membrane. Single, or occasionally united into threads..A. Desmidiaceae.

Cells cylindrical, without constriction. United into threads....B. Zygnemaceae.

A. Desmidiaceae.
  (*a*) Cells with only slight constriction.
    I. Cells lunate ....*Closterium.*
  (*b*) Cells with pronounced constriction.
    I. Cells twice as long as wide.
      1. Contour of cells 3 to 5 pointed..........................*Staurastrum.*
      2. Contour of cell round or oval; smooth.
        * Cells free ....*Cosmarium.*
        ** Cells united into a mass of jelly..........................*Micrasterias.*

B. Zygnemaceae.
Two axil star-shaped chromatophores in each cell........................*Zygnema.*
One or more peripheral spiral chromatophores..........................*Spirogyra.*

Chlorophyceae.

Grass or yellow green algae, single, or united into threads, plates, or masses. Form true spores, swarm spores, akinetes, and aplanospores. Constituting all of the green algae not included in the Conjugateae.

(*A*) Cells with one nucleus, frequently united into a gelatinous colony.
    (*a*) Vegetative state actively motile ....A. Volvocaceae.
    (*b*) Vegetative state not motile.
        I. Vegetative cell division for increase of colonies; without swarm spores ....B. Pleurococcaceae.
        II. Without vegetative cell division, cells single ....C. Protococcaceae.
        III. Cells united to form colonies of definite form..D. Hydrodictyaceae.
(*B*) Cells with one or many nuclei united to form simple or branched threads, or rarely one or more layered plates.
    (*a*) Vegetative cells with only one nucleus.
        I. Thallus of one or more layered plate, free or attached at base. E. Ulvaceae.
        II. Thallus consists of a simple or branched cell series.
            1. Unbranched filaments........................F. Ulothricaceae.
            2. Branched filaments........................G. Chaetophoraceae.
    (*b*) Vegetative cells with many nuclei, simple or branched filaments.
        I. Spore formation by union of swarming gametes.
            Filaments simple or branched, with base and point of growth. Division of filaments not dorsiventral........H. Cladophoraceae.

A. Volvocaceae.
(*A*) Cells single.
    (*a*) Cells with a thin white covering which does not form two valves.
        I. The integument thickened on one side. Cilia arising directly from the rounded forward end........................*Chlamydomonas.*
(*B*) Cells united to form definite colonies.
    (*a*) Round or oval colonies in a gelatinous envelope with cilia projecting from all sides.
        I. Colonies of 16 cells..................................*Pandorina.*
        II. Colonies of 32 cells..................................*Eudorina.*
        III. Colonies of very many cells forming a large sphere........*Volvox.*

B. Pleurococcaceae.
(*A*) Cells neither possessing gelatinous sheath nor embedded in jelly.
    (*a*) Cells single.
        I. Cells sickle-shaped or lunate..........................*Raphidium.*
    (*b*) Cells arranged in a plane.
        I. Colonies arising through division in one direction......*Scenedesmus.*

D. Hydrodictyaceae.
(*A*) Colonies hollow within.
    (*a*) Cells cylindrical, long ....*Hydrodictyon.*

E. Ulvaceae (marine).
(*A*) Thallus membranaceous, plate. Consists of two layers of cells.......*Ulva.*
(*B*) Thallus membranaceous, tube forming. Cells in older part slightly or not at all arranged in definite order..........................*Enteromorpha.*

F. Ulothricaceae.
(*A*) Cross walls of equal thickness.
(*a*) Swarm-spores present, escaping through a round hole in the cell wall.
I. Filaments long; cells all alike .... *Ulothrix.*
(*b*) Swarm-spores escape by breaking across the cell wall. Chromatophores consist of little orbicular plates.
I. The filament has one pedicle and numerous cells.......... *Conferva.*

G. Chaetophoraceae.
(*A*) Thallus not epiphytic, established with a basal cell or ground cell, seldom spherical or united into a spherical gelatinous mass.
(*a*) A clearly defined main stem present..................... *Draparnaldia.*
(*b*) No clearly defined main stem present.
I. Branches ending in hair points......................... *Stigeoclonium.*

H. Cladophoraceae.
Thallus consists of branched filaments. Branches irregular or forming a radial clump; akinetes absent .... *Cladophora.*

SCHIZOPHYCEAE.

(*A*) Plants consisting of a single cell, occasionally united into colonies by being embedded in a gelatinous matrix .... I. Coccogoneae.
(*B*) Plants having always more than one cell, forming simple or branched filaments, which may or may not be inclosed in an outer gelatinous layer or sheath .... II. Hormogoneae.

(I) Coccogoneae:
(1) Cells free or only slightly held together, not forming a definite colony .... *Chroococcus.*
(2) Cells held together in a gelatinous matrix and forming colonies of regular outline.
(*a*) Colonies at first solid, several rows of cells thick, becoming saccate and perforated................................. *Clathrocystis.*
(*b*) Colonies hollow, cells only on outer surface...... *Cœlosphaerium.*

(II) Hormogoneae:
(1) Cells generally differentiated into three kinds: (1) Vegetable cells; (2) spores; and, (3) heterocysts. The latter usually are of different color, clearer contents, and with thickenings in the walls adjoining the vegetative cells or spores ....(*a*) Heterocysteae.
(2) Cells in each filament undifferentiated. No heterocysts.
(*b*) Homocysteae.

(*a*) Heterocysteae:
+ Filaments irregularly interwoven and contorted, inclosed in a definite gelatinous mass.............................. *Nostoc.*
++ Filaments free or but slightly united.
Ø Heterocysts and spores intercalary.
* Filaments free or united in formless mass.... *Anabaena.*
** Filaments densely agglutinated in fascicles, often of considerable size .... *Aphanizomenon.*
ØØ Heterocysts and terminal spores contiguous.
Cylindrospermum.

(*b*) Homocysteae:
+ Filaments simple, with an evident sheath........... *Lyngbya.*
++ Filaments simple, sheath wanting or very slight, plants possessing a characteristic movement................ *Oscillatoria.*

METHOD OF APPLYING COPPER SULPHATE.

Before introducing the copper sulphate it is necessary to determine accurately the volume of water to be treated. This is imperative in the case of municipal supplies and large reservoirs, as an error in the the estimation might cause considerable inconvenience. Many cases will arise, however, in which a rough computation will be much more convenient and entirely practicable.

The method considered most practicable in introducing copper sulphate into a water supply has been outlined in a previous publication,[a] from which we quote:

> Place the required number of pounds of copper sulphate in a coarse bag—gunny sack or some equally loose mesh—and attaching this to the stern of a rowboat near the surface of the water, row slowly back and forth over the reservoir, on each trip keeping the boat within 10 to 20 feet of the previous path. In this manner about 100 pounds of copper sulphate can be distributed in one hour. By increasing the number of boats and, in the case of very deep reservoirs, hanging two or three bags to each boat, the treatment of even a large reservoir may be accomplished in from four to six hours. It is necessary, of course, to reduce as much as possible the time required for applying the copper, so that for immense supplies with a capacity of several billion gallons it would probably be desirable to use a launch, carrying long projecting spars to which could be attached bags each containing several hundred pounds of copper sulphate.

The substitution of wire netting for the gunny-sack bag allows a more rapid solution of the sulphate, and the time required for the introduction of the salt may thus be considerably reduced.

The temperature has such great influence on the effect of copper upon polluting forms that it is best to select as warm a day for treating as circumstances will permit.

STERILIZATION OF BACTERIA-POLLUTED WATER BY MEANS OF COPPER SULPHATE.

Treatment with copper sulphate is an effective and practicable means of sterilizing water polluted with certain pathogenic bacteria, and as an emergency method is applicable to both household and municipal conditions. It should prove particularly useful in very large water supplies accidentally or suddenly contaminated with typhoid bacilli and not provided with any adequate means of purification. Under such circumstances the case becomes not one of pure water versus water containing copper sulphate, but of sterile water containing an amount of copper not dangerous to health versus water and typhoid bacilli. The method formerly suggested[b] for treating a reservoir would undoubtedly be advisable in special cases of unusually great contamination when the water contained an abnormal amount of organic matter, but in general an epidemic could be controlled and quickly eradicated by a solution much weaker than the 1 to 100,000 listed as necessary for complete sterilization within twelve hours. One to 2,000,000 is sufficient in most cases, and even less than this quantity of copper is of decided benefit in certain kinds of water.

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[a] Bulletin No. 64, Bureau of Plant Industry, p. 25.

[b] Ibid., p. 33.

STERILIZATION OF THE WATER SUPPLIES AT COLUMBUS, OHIO, AND ALBUQUERQUE, N. MEX.

For many years Columbus, Ohio, has had a high typhoid rate, and the last few years have been a period of almost continuous epidemic. After some correspondence with this laboratory, Dr. McKendree Smith, health officer of the city, decided that copper sulphate offered a means of dealing with these exceptionally dangerous conditions. He accordingly treated the water supply and has recently made the following significant report:

> The Scioto River furnishes the main source of water supply to the city of Columbus, Ohio. Under ordinary conditions it is constantly menaced by innumerable sources of pollution. The limestone quarries, situated on both sides of the stream and extending 2 miles along the banks, employ over 300 men, many of whom are housed with their families in small buildings about the quarries on the extreme edge of the river's banks. A dozen or fifteen small houses, in which large Italian families live, are located in and about the old State quarries, which are also within a few feet of the river bank. A number of villages nestle dangerously near the river. The girls' industrial home (an institution caring for about 800) discharges its sewage directly into the river about 18 miles above the intake. Many small tributaries carry their share of pollution into the stream. These constitute the ordinary and always present dangers to the city's water supply. Recently, however, other grave dangers were added. During the past eight or ten months about 200 men, living in tents and temporary huts, employed in constructing a storage dam, clearing the river banks of trees and undergrowth, and in building the C., U. and W. traction line, by their presence and the manner in which they were compelled to live, increased to no inconsiderable degree the already too great dangers.
>
> To successfully police such a water supply is impossible, and as a temporary expedient, pending the completion of the purification plant, I resorted to the use of copper sulphate to keep the water supply free from disease-producing micro-organisms.
>
> My aim at first was to treat polluted tributaries and stagnant pools, which would drain into the river at the first rainfall, so as to render them harmless. The still water in deep pools, which upon analysis showed pollution, was also treated and at intervals, when the water in that part of the stream from which the city's supply was taken showed pollution, the treatment was applied directly to the water at the intake. At no time as the water enters the intake was it subjected to a treatment stronger than 1 part in 1,500,000. By carefully testing and treating the water of polluted tributaries and stagnant pools, it was seldom necessary to treat the river directly.
>
> Previously to the treatment of the water with copper sulphate only upon rare occasions was the water free from colon bacilli, but after the treatment was begun, from the 19th day of August to the 30th day of December, daily tests showed that the water was free of colon bacilli. During the heavy rainfall in the latter part of December, samples were taken from the hydrant tap at regular intervals of two hours both day and night. Notwithstanding the months of dry weather which pre-

ceded the rainfall, the colon bacilli were present for a period not longer than sixteen hours.

The treatment, which was begun and continued without the knowledge of the city authorities, was ordered stopped on January 5, 1905, after the daily papers published glaring accounts of the dangers attendant upon such treatment. To allay the fears of the people, five employees of the health department took daily for thirty days three-tenths of a grain of copper sulphate without any signs of discomfort or symptoms whatever.

During the month of August there were reported to the health office 52 cases of typhoid fever; September, 16 cases; October, 16 cases; November, 8 cases; December, 17 cases, only 4 of which used city water; January, 1905, 91 cases; February, 376 cases.

In January, 1905, not until the 14th was a single case reported that could be attributed to the use of the city water. On that day 3 were reported; on the 16th, 3; on the 18th, 3; on the 20th, 1; on the 21st, 3; on the 23d, 3; on the 24th, 14. From this date on the cases have averaged over 10 each day. No copper sulphate has been used since January 5, 1905.

The following tabulation of the data contained in the above report will perhaps show the results of the work more clearly:

Statement of typhoid cases reported in Columbus, Ohio, showing relation to use and nonuse of copper in the water supply.

	Month.	Typhoid cases reported.
No copper used	June	24
Do	July	33
Copper used after 19th	August	52
Copper used	September	16
Do	October	16
Do	November	8
Do	December	[a] 4
Copper discontinued after 5th	January	91
No copper used	February	376
Do	To March 27	279

[a] 17 cases were reported, but only 4 were users of city water.

In connection with the results obtained at Columbus should be mentioned the treatment of the water supply at Albuquerque, N. Mex. This was reported upon by John Weinzirl, city chemist, as follows:

> I desire to inform you that we used your copper sulphate treatment in the reservoir of our city water supply this summer with good results. This reservoir was full of algæ, and the water-supply company could not clear it before certain improvements in their plant were installed. The flavor of the water was rank; but two treatments made a great improvement, though the water was rendered cloudy by the partly decomposed organisms. We applied the treatment late in July and in August. During October we had a small epidemic of typhoid, perhaps 50 cases; the water supply was again treated with copper sulphate, and within three weeks the epidemic ended.
>
> I might add that during the first treatment the bacterial content of the water fell to one-fourth the original number.

STERILIZATION OF WATER BY MEANS OF METALLIC COPPER.

The effect of metallic copper upon *Bacillus typhi* in water is of considerable importance. For small amounts of water it has been found convenient and desirable in many cases to guard against bacterial contamination by employing copper tanks, and where frequent boiling can not be resorted to the use of copper may be regarded as the only possible safeguard. In some cases this may not be absolute, for our experiments upon water from various places and the experiments of other investigators show that the chemical constitution of the water under consideration is of the greatest importance. Water that contains a very large amount of matter in suspension is perhaps the most difficult to sterilize. Under these conditions twenty-four to forty-eight hours at room temperature would probably be necessary for complete sterilization through the agency of metallic copper tanks; on the other hand, metallic copper in water containing a large amount of organic acid, or free acid of any sort, would destroy all typhoid bacilli in two or three hours at the most. Complete sterilization is a standard to which even the best filters seldom attain, and under the most unfavorable conditions the reduction in the number of bacteria in water exposed to the action of metallic copper for twelve hours will be approximately as great as in a filtered water. The copper must be kept clean, not, as is popularly supposed, to protect the consumer from copper poisoning, but because it is possible for the metal to become so coated with foreign substances that there is no longer any contact of copper and water, and hence no antiseptic action.

An interesting corroborative fact is the antiseptic property of copper coins. Lately considerable work has been done on this problem by the department of health of the city of New York,[a] and, as was to be expected, it was found that copper and nickel coins smeared with cultures of pathogenic bacteria, such as *Bacillus diphtheriae*, were completely sterile in a few hours, and that the same was true to a less degree of silver coins.

In a recent article, Dr. Henry Kraemer reviews the applicability of the germicidal power of copper to drinking water, and his results with the Philadelphia water show that standing four hours in the presence of copper foil completely destroyed both *Bacillus typhi* and *Bacillus coli*.

Doctor Kraemer's conclusions are quoted below:[b]

> In filtration processes it is generally understood that both typhoid and colon organisms are the first to be eliminated, and without waiting to make a systematic study of the organisms which persist as well as those which are killed in the copper treatment of water, I thought it well to test the method by using water containing these organisms alone. As results depend in some measure upon the method used, I will try to outline my method before giving my results.
>
> 1. Water under three different conditions was employed: (*a*) Distilled water which was prepared from tap water by first treating it with potassium permanganate and then distilling it two or three times by means of apparatus constructed entirely of

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[a] Report of Dr. Wm. H. Park, March 1, 1904.

[b] Henry Kraemer. The Efficiency of Copper Foil in Destroying Typhoid and Colon Bacilli in Water. American Medicine, February 18, 1905, Vol. IX, No. 7, p. 275.

glass; (*b*) filtered tap water, prepared by means of a Berkefeld filter attached to a copper spigot; (*c*) tap water, collected after being allowed to run through a copper spigot for five minutes. All of these were sterilized in an autoclave at 110° for thirty minutes.

2. The cultures of typhoid and colon which were used were pure cultures developed in bouillon for eighteen hours to twenty-four hours.

I may say that every single experiment which we have conducted * * * shows that copper foil is exceeding toxic to colon and typhoid bacilli, particularly the latter.

It will be seen by consulting the tables that in the filtered water, to which no copper foil had been added, the typhoid organisms did not grow and multiply as was the case with the tap water and distilled water, although there was a larger number of organisms to begin with. This also applies in a measure to the colon bacilli, with which there is a very marked inhibiting action in those growing in the filtered water.

At first I was inclined to attribute this diminution in the number of the organisms to minute traces of copper in the flasks, but subsequent experiments showed that this was not the case. I am, therefore, inclined to attribute these rather anomalous results to the presence of extremely small quantities of copper dissolved by the water in its necessarily slow passage through the copper spigot to which the filter was attached. This is a phase of the problem to which I am devoting my attention at present, as it certainly opens up an interesting side of this subject.

Even granting the efficiency of the boiling of water for domestic purposes, I believe that the copper-treated water is more natural and more healthful, inasmuch as the various inorganic constituents, particularly the salts of calcium and magnesium, are in a more soluble and assimilable condition, being furthermore less concentrated, at the same time the natural gases of the water being retained.

From the experiments thus far conducted the following conclusions may be drawn:

1. The intestinal bacteria, like colon and typhoid, are completely destroyed by placing clean copper foil in the water containing them.

2. The effects of colloidal copper and copper sulphate in the purification of drinking water are in a quantitative sense much like those of filtration, only the organisms are completely destroyed.

3. Pending the introduction of the copper treatment of water on a large scale the householder may avail himself of a method for the purification of drinking water by the use of strips of copper foil about 3½ inches square to each quart of water, this being allowed to stand over night, or from six to eight hours, at the ordinary temperature, and then the water drawn off or the copper foil removed.

Doctor Pennington, of Philadelphia, has reported[a] results of the board of health laboratory, showing complete sterilization of infected tap water within fifteen minutes by means of copper foil.

Rideal and Baines[b] have carried on some experiments concerning the germicidal effect of copper. Evidently they added too much of the culture to be tested to the treated water. The high concentrations required according to their tables to produce complete sterility can be explained only by the presence of considerable amounts of albuminoid matter, and under these circumstances the condition is comparable to sterilizing sewage rather than sterilizing drinking water.

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[a] At a meeting of the Washington Academy of Sciences, January, 1905.

[b] S. Rideal and E. Baines. The Suggested Use of Copper Drinking Vessels as a Prophylactic against Waterborne Typhoid. Journal of the Sanitary Institute, XXV, 1904.

Their experiments with metallic copper, though too few to be themselves at all conclusive, are entirely in accord with the results of the Laboratory of Plant Physiology as formerly published.

COPPER IN THE DISPOSAL OF SEWAGE.

In connection with the sterilization of water by means of copper the possibility of using this metal in the sanitary disposal of sewage should be mentioned. This is well described by Rideal,[a] from whom we quote:

> The soluble salts of copper have a distinctly poisonous action on bacteria. They coagulate albumen and combine with most of the organic acids present to form non-putrescible salts. They absorb sulphureted hydrogen, ammonia, and compound ammonias, and therefore combine with "ptomaines." In fact, copper salts rank next to mercury in power as antiseptics.
>
> * * * * * * *
>
> Kroncke[b] contended that, for sewage treatment, compounds having a great affinity for sulphur should yield the best results. He has experimented with cuprous chloride as being a salt which fulfills this condition, is readily prepared, very easily removed from solutions, and becomes much less poisonous when oxidized. He used the following method for the purification of water: Cuprous chlorid amounting to one twenty-thousandth of the liquid to be treated, and ferrous sulphate (as far as possible free from ferric) to the extent of one fifty-thousandth, are mixed with the water. After six hours one one hundred-thousandth part of lime is added, and agitated for one hour. After settling for one and a half hours, and filtration through sand, the water, which originally contained 40,000 to 50,000 organisms per cubic centimeter, was found to be completely sterilized, clear, almost colorless, and free from iron and copper. The sand filter can be used a long time without cleansing. Schumburg[c] reports that a water treated with cuprous chlorid solution and then with lime was free from germs after six hours.

COPPER SUPPLEMENTING THE USE OF FILTERS.

It appears from the examination of a considerable number of filters in this country that the officials in charge of municipal waterworks are not justified in assuming that filtration is the absolute guarantee against a disease-laden water that it is popularly supposed to be. The number of unavoidable accidents which are known to occur in properly managed filters, to say nothing of the willful and sometimes criminal methods resorted to in order to bring the supply of water up to the daily demand, are factors which are not generally considered by the public. The mere fact that filters are installed seems to warrant neglect of the source of the water, and as a mistake or an accident usually can not be detected by the public until the death rate increases markedly, filtration as administered in a considerable number of cases has resulted in a condition more dangerous than if no filter existed. The sooner that it becomes generally known that any sort of filtration is a most delicate process, depending upon skilled manipulation for maximum efficiency, the better it will be both for filtration and the consumer of water. That it is not an unheard of practice to force considerably larger quantities of water through a sand filter than it can possibly free from disease germs (even resorting to spading over the sand to hasten the flow) ought to be understood by all those using such water. The direct pumping of polluted river water into the filtered water for the purpose of making up the daily supply has been resorted to, and the occurrence of breaks in storage basins, conduits, etc., has more than once afforded opportunities for the dangerous contamination of the filtered water.

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[a] Rideal. Disinfection and the Preservation of Food, New York, 1903; pp. 156, 157.

[b] Jour. für Gasbeleucht, XXXVI, 513.

[c] Chem. Centr., 1900, II, 203.

At the present time the only known method of immediately rendering a contaminated water supply safe and keeping it so until the source of pollution is removed seems to be the use of copper. This treatment is not designed to supplant efficient filtration, however, and should never be expected to take its place. The use of copper for removing a temporary contamination is necessarily a remedy and should be used as such. As much care is demanded of the sanitary engineer or biologist in determining the necessity for treatment and the proper quantity to be used as is demanded of a doctor in determining the dose for a sick person. A pure water should not be treated, just as a well person should not take medicine.

The existing methods of sewage disposal and water purification are particularly unfortunate. To deliberately contaminate a water and then try to purify it seems ridiculous, yet this is precisely what is now being done in a number of communities. The ultimate solution of the problem of water supply must depend upon proper sewage disposal as well as the proper care and policing of the watersheds and wells. Until this revolution of methods shall have taken place, the makeshifts—filtration, and treating with copper—are the only remedies applicable on a large scale.

COPPER TREATMENT AND FILTRATION AT ANDERSON, IND.

By the invitation of Mr. C. Arthur Brown, sanitary engineer of the American Steel and Wire Company, acting at the time as the representative of the Jewel Filtration Company, and through the courtesy of the officials of Anderson, Ind., the Laboratory of Plant Physiology was enabled to undertake a series of experiments upon the effect of copper treatment of water in connection with mechanical filtration. The filter plant had been recently completed, and these experiments were carried on at the time of the preliminary testing of the efficiency of the filters.[a] The water supply at Anderson, Ind., offered exceptional opportunities for demonstrating the efficiency of copper in removing intestinal bacteria. The water is drawn from the White River, into which the city of Muncie empties its entire sewage. There are no falls or rapids in the 25 miles separating these two cities, and during the entire four weeks of the test conducted on the use of copper in connection with filtration the river was icebound, making a closed conduit for the diluted sewage from Muncie and the smaller towns still farther up the river. The water was very high in albuminoid and free ammonia, and exceptionally high in chlorin, due to the salt water from the gas field above Muncie. The turbidity was very low and the color slight. Fortunately for the thorough testing of the value of copper, the filters, owing to some structural defects, were unable to effect a high percentage reduction of bacteria at this time. The number of bacteria in the river ranged from 13,000 to 155,000 per cubic centimeter at irregular intervals during the four weeks' test, usually remaining above 50,000. The number of bacteria in the filtered water varied between 15,000 and 400 per cubic centimeter, usually remaining above 3,000.

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[a] Professor Burrage, professor of sanitary science at Purdue University, was retained by the city of Anderson as its representative, as well as Dr. S. C. Norris, city chemist and bacteriologist. Mr. Brown acted as the representative of the filtration company.

For ten days, February 2–11, 1905, alum was used as a coagulant, but for water of this character it seemed impossible to get a proper coagulation with 1, 2, or 3 grains of alum per gallon, either with or without the addition of lime. *Bacillus coli* was always present in the river water and usually in the filtered water, and was identified by gas formation, reduction of neutral red, proportion of carbon dioxid, growth on milk, potato, gelatin, litmus agar, and formation of indol. On February 11, instead of aluminum sulphate, iron sulphate containing 1 per cent of copper sulphate was introduced in quantities of 1½ grains per gallon of water.[a] Lime was added, 2 grains per gallon. The treatment was continued four days, and during that time only once was there any indication of the presence of *B. coli* in fermentation tubes inoculated with 1 c. c. samples of filtered water, and this occurred immediately after a leak developed in the air pipe of the washing system that allowed unfiltered water to pass into the pipes. On the 15th of February, the amount of iron sulphate containing 1 per cent of copper sulphate was raised to 4½ grains per gallon. This quantity was found to be too great, and at midnight the amount of the coagulant was reduced to 2¼ grains.[b] The valve controlling the iron solution caught on this change and for nearly an hour no iron or copper was applied to the raw water. This allowed polluted water to reach the clear well, and at the next washing the filters were again contaminated, and samples from two of them developed typical *Bacillus coli*. The following five days

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[a] 0.015 grain copper sulphate per gallon—approximately 1 part of copper sulphate to 4,000,000 parts of water.

[b] 0.0225 grain copper sulphate per gallon—approximately 1 part of copper sulphate to 2,500,000 parts of water.

B. coli developed but once, and this was immediately following the reappearance of the leak in the air pipe.

Iron sulphate containing one-half per cent copper sulphate was now applied at the rate of 1.5 grains[a] per gallon; *Bacillus coli* was eliminated during the two days that this mixture was used. Iron sulphate containing only one-fourth per cent copper sulphate[b] was substituted during one day. This amount was insufficient to eradicate completely the *B. coli*, and two of the filter samples contained this organism.

Pure iron sulphate was then used at the rate of 3 grains per gallon, and *Bacillus coli* developed from samples of each filter. Iron sulphate containing 1 per cent copper sulphate was substituted for the greater part of the pure iron salt, and in the following samples no *B. coli* developed in the filtered water.

From the preceding experiments there seems to be no doubt that the filtering of polluted water of this character through the layer of coagulum of iron and copper which forms on the filter bed brings the bacteria borne in the water into contact with the precipitated copper for a sufficient length of time to destroy *Bacillus coli*, and as *Bacillus typhi* is still more sensitive to the action of copper it too must necessarily be removed from the filtered water.

The last samples of the test have been omitted from previous discussion, as the point illustrated by them is of an entirely separate character. Shortly before these samples were taken, ten gallons of a bouillon culture of *Bacillus prodigiosus* were introduced into the feed pipe of the filters, and the following and last samples all showed *Bacillus coli* present. This emphasizes the fact brought out in a former bulletin[c] that the toxicity of copper sulphate is greatly reduced if the amount of organic and albuminoid matter is greatly increased. A proper comprehension of the constitution of a water is therefore necessary for successfully treating to remove bacteria, just as it is desirable for treating to remove algæ.

It should be reiterated that the results of investigators with reference to the germicidal action of copper in bouillon, milk, or solid media are not comparable to results upon the toxic action of copper in water of ordinary purity. Nor can results obtained with unknown organisms, nor results obtained with *Bacillus anthracis*, *Bacillus tetanus*, and such spore-forming resistant bacteria be compared with results obtained with *Bacillus typhi* and *Microspira comma*.

One of the objections to the use of copper sulphate in water supplies has been that there was a chance of appreciable amounts of copper reaching the consumer. Considering the harmlessness of copper, this is a theoretical rather than a practical objection, and is answered in the present instance. The copper is all precipitated and the insoluble coagulum of iron and copper is caught upon the filters.

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[a] 0.0075 grain copper sulphate per gallon—approximately 1 part of copper sulphate to 8,000,000 parts of water.

[b] 0.00375 grain copper sulphate per gallon—approximately 1 part of copper sulphate to 15,000,000 parts of water.

[c] Bulletin No. 64, Bureau of Plant Industry, p. 29.

Table showing the presence or absence of Bacillus coli per cubic centimeter in samples from various sources at Anderson, Ind.

Chemicals applied (in grains per gallon) and time of sampling.		River.	Settling basin.	Filter No. 1.	Filter No. 2.	Filter No. 3.	Filter No. 4.	Tap.
1 grain alum:								
February 2	a. m.	+	+	+	+	+	+	+
	p. m.	+	+	+	+	+	+	+
February 3	a. m.	+	+	+	+	+	+	+
	p. m.	−	−	−	+	+	−	+
2 grains alum: February 4, a. m.		+	+	−	−	+	−	+
3 grains alum:								
February 4, p. m.		+	+	−	+	+	−	−
February 5	a. m.	+	+	−	−	−	−	+
	p. m.	+	+	−	+	+	+	+
February 6	a. m.	+	+	+	+	−	+	+
	p. m.	+	+	+	+	+	+	−
February 7	a. m.	+	+	+	+	+	+	+
	p. m.	+	+	+	+	+	−	+
February 8	a. m.	+	+	−	−	−	−	+
	p. m.	+	+	−	−	−	+	−
February 9, a. m.		+	+	−	+	+	−	−
2 grains alum:								
February 9, p. m.		−	+	−	−	−	+	......
February 10, a. m.		+	+	+	+	+	+	+
1½ grains alum, 2 grains lime:								
February 10, p. m.		+	+	+	−	+	+	+
February 11, a. m.		−	−	−	−	−	−	+
1½ grains iron sulphate, 0.015 grain copper sulphate, 2 grains lime:								
February 11, p. m.		+	−	−	−	−	−	+
February 12, a. m.		+	+	−	−	[a] +	−	......
1½ grains iron sulphate, 0.015 grain copper sulphate, 1½ grains lime:								
February 12, p. m.		+	−	−	−	−	−	−
February 13	a. m.	+	−	−	−	......	−	−
	p. m.	−	+	−	−	−	−	−
February 14, p. m.		+	+	−	−	−	−	−
February 15	a. m.	+	−	−	−	−	−	−
	p. m.	+	−	−	−	−	−	−
2¼ grains iron sulphate, 0.0225 grain copper sulphate, 1½, 1, and ¾ grains lime:[b]								
February 16	a. m.	+	+	−	−	[a] +	−	−
	p. m.	+	+	−	[b] +	−	[b] +	+
February 17	a. m.	+	+	−	−	−	−	+
	p. m.	+	+	−	−	......	−	−
February 18, p. m.		−	+	−	−	−	−	−
1 grain iron sulphate, 0.0075 grain copper sulphate, ¾, and 1 grain lime:								
February 19	a. m.	−	−	−	−	−	−	−
	p. m.	−	−	−	−	−	−	−
February 20	a. m.	+	+	+	−	−	−	−
	p. m.	+	+	−	−	−	−	−
1 grain iron sulphate, 0.00375 grain copper sulphate, 1 grain lime:								
February 21	a. m.	+	−	−	−	......	−	−
	p. m.	−	−	−	−	......	−	−
3 grains iron sulphate, 1 grain lime:								
February 22	a. m.	+	+	+	−	......	+	+
	p. m.	+	+	+	+	+	+	+
3 grains iron sulphate, 0.03 grain copper sulphate: February 23, a. m.		+	+	−	−	−	−	......

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[a] The presence of *Bacillus coli* in filter No. 3 on February 12 and 16 is due to a leak which developed in the air wash pipe, allowing unfiltered water to pass into the pipes.

[b] The amount of iron sulphate was raised to 4½ grains at 6 p. m. on February 15, but this was too much for the filters to accommodate, and at midnight the amount was reduced to 2¼ grains; at this time the valve stuck and for some time no iron or copper was introduced into the water. This allowed contaminated water to pass the filters, and at the next washing the contaminated water from the clear well again contaminated the filters, and near enough the time of sampling to show *Bacillus coli* in two of the samples.

OBJECTIONS TO THE USE OF COPPER SULPHATE.

During the past year several articles have appeared, some of a more or less alarmist nature, containing adverse criticism of the copper sulphate method of treating reservoirs. In some instances the efficiency of the method is questioned; in others, objection has apparently originated in the prejudice which obtains in some quarters, due to the supposed ill effects upon the human system of the absorption of small quantities of copper.

In view of the year's experience in practical applications of the treatment, nothing need be said further in behalf of its efficiency.

The existence of conditions which might make treatment with copper undesirable is not overlooked, but, so far as is known, these are peculiar to certain localities and of a nature which presents difficulty from the engineering rather than the hygienic standpoint.

The appearance of resistant forms after the removal of the polluting organism by means of dilute solutions of copper sulphate has been mentioned by engineers as possibly producing a worse condition than that previously existing in the water. Certainly such an objection would have been worthy of careful consideration had it been raised before an opportunity had occurred to test the efficiency of copper sulphate as an algicide. Experience with all water supplies treated, however, proves that such a difficulty is not to be feared and that the destruction of the algæ is so rapid as to prevent the evolution of similarly contaminating forms resistant to copper.

The case which has been under observation for the longest time is that at Ben, Va., where, in January, 1902, cress beds were treated for the eradication of Spirogyra. Conditions were such as to be unusually favorable for the development of the algæ, and certainly if a form resistant to copper could be produced under natural conditions it would have appeared here. After the first treatment was made several subsequent applications of copper in diminishing quantities were resorted to, but the algæ, instead of being more difficult to eradicate, were easier and easier to kill, and in a recent letter Mr. Moomaw, proprietor of the cress beds, states that the algæ have been completely destroyed and no other form has appeared.

OPINIONS OF TOXICOLOGISTS UPON THE EFFECT OF COPPER SULPHATE.

In a few instances objection has been made to the use of copper sulphate, even in the minute quantities shown to be efficient for the purpose of sterilizing water. Some authors have held that anything which would destroy algæ and bacteria would likewise kill man,[a] while others have maintained that nothing is known of the effect of the infinitesimal dose which might be administered.[a] The opinions of eminent toxicologists seem fully to answer both the violent objections and the conservative doubts as to the possible injurious effect upon the human system of copper thus used.

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[a] Medical Bulletin, October, 1904.

The literature relating to the harmlessness of copper is so voluminous as to make it impossible even to refer to most of it, but a few of the more recent articles upon the subject are quoted in order that the authorities who may desire to improve the character of the water supply under their control may have the benefit of the experiments of those who have investigated the effect of this metal upon man and other animals.

Dr. Henry Kraemer, in an article in the American Journal of Pharmacy, December, 1904, wrote as follows:

The toxic influence of even very minute quantities of colloidal copper and of copper sulphate on certain micro-organisms having been pretty well established, the only other question of importance that arises in connection with their use for the purification of water supplies containing pathogenic organisms and algæ is the one as to their effects on man. Inasmuch as this phase of the question is dependent upon physicians and pharmacologists for its elucidation, the editor of this journal has asked several members of the medical profession to discuss it.

It is to the credit of the medical profession that while some of those asked to contribute to this discussion have more or less positive convictions on the subject, others have been frank to say that their observations and experience in this line of investigation have not been sufficient to warrant them in giving an opinion at this time. One pharmacologist writes: "As I understand the purification method, the quantities of copper remaining in solution are so extremely small that they would scarcely be harmful."

Another eminent pharmacologist writes that when he was consulted by a city official to give an opinion as to whether 1 part of copper in 1,000,000 parts of water would be harmful, he replied that, "Assuming for purposes of argument that the copper remains in solution and is not deposited or rendered insoluble, this small quantity could not be harmful to our citizens, even if they drank such water for a few days, since our ordinary food, as bread, meat, etc., all contain from 2 to 3 parts in the million. Some tissues, like the liver, contain as high as 30 parts in the million."

Up to the time of going to press replies were also received from Doctor Hare, professor of materia medica and therapeutics in the Jefferson Medical College, and from Doctor Holland, dean and professor of medical chemistry and toxicology in Jefferson Medical College. Their replies are as follows:

My Dear Professor Kraemer: In reply to your note let me state that small doses of copper exercise, so far as is known, a stimulant effect upon nutritional processes. I do not think that we have any information in regard to the infinitesimal quantities which are present in water when treated by the copper method, but it is incredible that they could exercise any deleterious influence. Certainly the improbable deleterious influence of infinitesimal quantities of copper when compared to the certain evil influence of micro-organisms amounts to nothing.

Very truly yours,

H. A. Hare.

Philadelphia, *November 14, 1904.*

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[a] American Medicine, November 12, 1904.

Mr. Henry Kraemer,
Editor of American Journal of Pharmacy.

Dear Sir: In this paper on purification of water by copper I think that Doctor Moore shows conclusively that water supplies can be freed of pathogenic bacteria and algæ promptly, cheaply, and efficiently by that means. The question remaining to be answered is, Can this purification be done with entire safety to those drinking the water?

Until comparatively recent times it has been thought that the slow introduction of minute doses of copper was injurious to the tissues by causing such pathological changes as are known to be due to certain other metallic poisons, such as lead, arsenic, and mercury. But Bernatzic has proven that to produce toxic phenomena with copper salts it must be given freely and intentionally, and even then the subject spontaneously recovers when the administration ceases. When a student of medicine I was made aware of the harmlessness of copper sulphate in small doses. Quinine was very expensive then, and in the dispensary practice of a malarious region some cheaper substitute was needed. Hundreds of cases were treated with a combination of the sulphates of cinchonine, iron, and copper. About one-eighth of a grain of sulphate of copper was given several times daily in this routine prescription for a tonic and antiperiodic.

I do not remember that any untoward symptoms developed, though they were not unexpected, as the books then taught that copper salts were irritants. So they are, but only in doses much larger than one-eighth of a grain. We saw no cumulative effects. Lehmann and his pupils found that a man could take 1 to 2 grains of copper as sulphate and acetate daily in peas and beans divided into two meals without effect.

The highest sanitary authorities appointed to investigate this matter have reported that "copper in the amounts found in canned goods is not capable of injury to health."

Metallic copper is not a poison. Surgeons have used copper wire for suturing wounds without noticing local irritation; children swallow copper pennies daily without injury to the digestive tract. As copper is present in almost all our food it is not surprising to learn that each of us takes daily about one milligram of copper, and that it is found regularly in our tissues. I see no reason to fear copper if the amounts never exceed the small proportion stated by Doctor Moore as entirely adequate for the purification of water supplies.

J. W. Holland.

Philadelphia, *November 15, 1904.*

Dr. A. R. Cushney, in his Treatise on Pharmacology and Therapeutics,[a] writes:

Small quantities of copper may be taken for indefinite periods without any symptoms being induced, so that so far as man is concerned the general action of copper is unknown. * * *. On the other hand, copper is a deadly poison to several of the lower plants. Thus, traces of copper added to the water in which they live, destroy some of the simpler algæ, and Naegeli asserts that 1 part of copper in 1,000,000,000 parts of water is sufficient to kill these plants. * * * Locke found that the traces of copper contained in water distilled in copper vessels were sufficient to destroy Tubifex (one of the annelid worms) and tadpoles, while Bucholtz states that the development of bacteria is stopped by a solution of copper sulphate under 1 per cent in strength. Copper thus seems to have a very powerful poisonous action on certain living forms and to be harmless to others, and the subject deserves further investigation. It is possible that it may prove to act prejudicially to some human parasites, and it is certainly less dangerous to man than many other remedies used as parasiticides and disinfectants.

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[a] Pharmacology and Therapeutics, New York, 1899, p. 159.

Dr. R. A. Witthaus[a] has published a similar opinion:

> The opinion, formerly universal among toxicologists, that all the compounds of copper are poisonous has been much modified by later researches. Certain of the copper compounds, such as sulphate, having a tendency to combine with protein and other animal substances, produce symptoms of irritation by their direct local action when brought in contact with the gastric or intestinal mucous membrane. One of the characteristic symptoms of such irritation is the vomiting of a greenish matter, which develops a blue color upon the addition of NH_4HO.
>
> Cases are not wanting in which severe illness, and even death, has followed the use of food which has been in contact with imperfectly tinned copper vessels. Cases in which nervous and other symptoms referable to a truly poisonous action have occurred. As, however, it has also been shown that nonirritant, pure copper compounds may be taken in considerable doses with impunity, it appears at least probable that the poisonous action attributed to copper is due to other substances. The tin and solder used in the manufacture of copper utensils contain lead, and in some cases of so-called copper poisoning the symptoms have been such as are as consistent with lead poisoning as with copper poisoning. Copper is also notoriously liable to contamination with arsenic, and it is by no means improbable that compounds of that element are the active poisonous agents in some cases of supposed copper intoxication. Nor is it improbable that articles of food allowed to remain exposed to air in copper vessels should undergo those peculiar changes which result in the formation of poisonous substances, such as the sausage or cheese poisons, or the ptomaines.

MEDICINAL USE OF COPPER.

The probable medical value of copper in treating typhoid and related diseases was suggested in the former bulletin. Salts of this metal have been used for many years in treating dysentery, and in one instance at least diphtheria has been treated with copper sulphate with remarkable success.

The use of copper in treating typhoid fever was reported upon by Dr. Lucien F. Salomon, of New Orleans.[b] We quote from recent letters from Doctor Salomon, as follows:

> Two years ago I published the results of my experience claiming to *cure* typhoid fever with the arsenite of copper. Subsequent experience in its use confirms the claim then made. I use the word "*cure*" because within seventy-two hours after beginning its administration in a given case, what was a severe case of typhoid becomes converted into a simple benign fever, and the patient recovers in ten or twelve days. (May 10, 1904.)
>
> I have clinical records of a number of cases treated with arsenite of copper since the publication of my article, all of which show the same good result. (June 11, 1904.)

As has been shown in Bulletin No. 64 of the Bureau of Plant Industry, the toxic effect of copper upon cholera germs is even greater than upon typhoid bacilli.

The following account of some practical experience with the effect of copper upon cholera bears out this laboratory's experiments, and there are numerous instances in this country where the beneficial effect of some form of copper upon cholera epidemics has been observed:

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[a] The Medical Students' Manual of Chemistry, New York, 1902, p. 207.

[b] The published article appeared in the New Orleans Medical and Surgical Journal for June, 1902.

Dr. Arthur de Noé Walker, in a pamphlet entitled "The Prophylactic Power of Copper in Epidemic Cholera" (London, 1883[a]), wrote as follows:

> When the following facts receive the attention they deserve Asiatic cholera will cease to destroy mankind.
>
> In the year 1849, and again in 1851, Tuscany was ravaged by a severe epidemic of Asiatic cholera, and for the sixth time I had every opportunity of observing and studying this, perhaps, the most fatal disease of modern times. While noting down some of the observations published by Professor Betti on both epidemics, the following paragraphs were particularly remarked and transcribed:
>
>> I believe I ought not to conclude the history of the epidemic of Asiatic cholera that afflicted the city of Prato and the adjacent country without saying a few words about a particular industry carried on in the vicinity of that city, and state the effects of the same on the workmen.
>>
>> It is well known that in the valley of the Bisenzio, distant only 4 miles from Prato, and precisely at a place called La Briglia, are the furnaces where the copper ore excavated from Mount Romboli is smelted. With the object of bringing to light the influence that process might have on the disease, I deemed it opportune to institute certain special investigations, and having interested the government authorities on the subject, the following intelligence was obtained:
>>
>> The workmen engaged at the smelting furnaces at La Briglia, in the valley of the Bisenzio, when the epidemic broke out in Prato and in the adjacent country, were 58, which number, added to the individuals composing their respective families living within a radius of about 3 miles from the furnaces, made up a total of 150 souls.
>>
>> Among all those individuals, not only no case of real Asiatic cholera, but not even a sporadic case, nor a case of cholerine, occurred.
>>
>> I was, moreover, assured that not one of them was affected by even the slight gastric and intestinal disturbance so common in those living in localities attacked by the deadly malady, although they—the workmen and their families—live in damp situations along the Bisenzian torrent. Their diet is that of all ordinary laborers.
>
> The value of this fact was, in my estimation, at once doubled by another, noted by Professor Betti. He states that the disease attacked, and in every instance proved fatal, to many living in the valley of the Bisenzio and in the neighborhood of the smelters' families, but that those so attacked and succumbed had, directly or indirectly, nothing whatever to do with the furnaces nor with any of the workmen employed in smelting the ore.
>
> I must here note, on evidence I have myself collected, that one workman, thoroughly inquinated and having his person and garments dusted over by a prophylactic agent, consequent, e. g., on a sufficiently long attendance at a smelting furnace, becomes an efficient means or vehicle whereby all the members of his household may become protected by that same agent. This was assumed the moment the professor's observations were read. Thus, conversely, an accoucheur, or a monthly nurse that has attended a case of puerperal fever, fatal or not, is liable to affect scores of other women. Some contagia frequently are, as is well known, conveyed by one healthy individual to many others; and it was simply inferred that if contagious matter can thus pass from one person to many, it was not at least unlikely that a prophylactic agent might likewise pass from one member to others of the same family.
>
> Observations I need not here detail have proved to me that the assumption entertained when Betti's observation was read is now no longer an hypothesis.[b]
>
> Workmen engaged at smelting furnaces, or otherwise employed in working the metal, become thoroughly impregnated with the ore, which adheres all over the

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[a] Written twenty years previously. Published with a few additions in 1883.

[b] "On the Effects of Copper upon the System." Proceedings of the Clinical Society of London. Vol. 3.

common integument. An appreciable quantity may be easily obtained by burning some of the hair of men constantly engaged in smelting the ore.

After reading Professor Betti's observations every available means and opportunity was sought with the object of ascertaining whether the same immunity could be verified at other establishments where copper was worked in any sort of way. The result proved that not one person habitually engaged in working copper had been attacked by cholera, not even among those whose work simply consisted in polishing the metal.

The indefatigable Frenchman, Burq, has published a valuable work on the preventive and curative action of copper in epidemic cholera, in which he honestly and courageously quotes Hahnemann, proving that he followed in the steps of that extraordinary genius. But Burq, while still a medical student attending lectures, spared no expense, no pains, no trouble, in order to prove this most important fact. He allowed nothing to deter or to discourage him—not even the insults of the Academy of Science and Medicine nor the slights of some physicians holding important appointments under the French Government.

"One day," he says, "some private business led me to visit an important copper foundry in the Rue des Gravilliers. In the course of a casual conversation with one of the workmen I learned that they, as well as all the inhabitants of the establishment, numbering about 200, had, in 1832, and again in 1849, been exempt from cholera. The fact of such complete immunity, although it might have been due to a mere fortuitous exception, greatly surprised me, and I asked myself if metals might not have other properties especially antagonistic to cholera besides those I had discovered. Nevertheless, I soon began to lose sight of the fact, when a similar observation, with a sort of pertinacious tenacity, again presented itself to my notice, and notably in connection with other copper foundries situated in the same street, where from 400 to 500 workmen and others occupying the premises had, one and all, been absolutely free from the disease. This strange and all-important immunity could not, I reflected, be due to the healthiness of the district or to the exceptionally healthy state of the houses, all of which, without exception, were as poor as those generally selected for foundries of any kind. Neither could it be ascribed, as I have said, to the good hygienic condition of the inhabitants generally nor to the exceptionally low mortality of the neighboring habitations. It became, therefore, impossible for us to look upon this complete immunity simply as a coincidence, and from that moment I allowed myself no rest nor respite until I had proven without a shadow of a doubt this peculiar property of copper—a property I had hitherto based on a mere supposition. In order to obtain this important result, as I said in 1853, I gave myself up and devoted myself to pursue a vast inquiry, of which the following are the chief results:

"In Paris, I personally visited 400 workshops, and other places where metals are worked; from the most modest, where four, five, or ten workmen are employed, to extensive establishments, where the workmen may be counted by hundreds, as may be done at Messrs. Cail & Cave's establishment. I also visited the iron founderies in the suburbs of Saint Marceau and Saint Jacques, and the type foundry in the Rue Vangirard, the manufactories of Messrs. Lagoutte, Calla, Gouin, and Farcot. At Chapelle and Saint Ouen, the founderies of Messrs. Cail & Co.; at Chaillot and Grenelle; and the manufactory of castors in copper in the suburbs of Saint Antoine; and, finally, all the workers in bronze at Marais. I then put myself in communication with the presidents, treasurers, and secretaries of workmen's unions, and likewise questioned the workmen themselves at their homes or lodgings. Contemporaneously, I wrote to the proprietors, directors, and physicians of our chief manufactories, forges, wire makers, and metal beaters. To the mayors and magistrates of towns where, as at l'Aigle and Villedieu, the inhabitants are almost all occupied in working metals, requesting them to give me information regarding the course and progress the epidemic had taken and made in their respective localities. Not satisfied with having obtained accurate information regarding a vast number of persons, I communicated with the English, Swedish, and Russian ambassadors, with Professors Huss, of Stockholm; Montferrand, of St. Petersburg (director of the Siberian mines belonging to Prince Demidoff), who afforded me information respecting no less than 46,500 miners of both sexes. Finally, I obtained information from the chief and most extensive metallurgic establishments in Europe, the cutlers of Sheffield, the copper refiners in the principality of Wales; the boiler makers of Birmingham; the mines at Phalen of Linkepening, in Sweden; at Stolberg, at Silecia, and many others. And it was after a correspondence and inquiries of every kind, carried on for a period of five months, concerning a population of 200,000 souls, that we believed we had the right to address the Academy of Medicine and Sciences, in a memoir, concluding as follows:

"I. Complete immunity from cholera of the immense majority of all workmen whose calling necessitates their being habitually in contact with copper dust.

"II. Copper and its alloys, brass and bronze, permanently applied to large surfaces of the common integument, are a most precious preventive, which ought in no wise to be neglected and can cause no inconvenience. If these means leave something to be desired as a prophylactic, it will probably be found expedient to reduce the metal to an impalpable powder and to ingest a few pinches.

"III. In the treatment of cholera, copper, opportunely administered, whether in copper filing alone or in any other form which experience shall determine, affords the greatest probability of proving in the hands of the physician a powerful means of cure."

Doctor Clapton[a] describes the "habitual lassitude and giddiness" of some of the laborers engaged in copper works, and more violent symptoms in two cases. From his description all the laborers were evidently saturated with salts of the metal, yet disagreeable effects, even under such conditions, are undoubtedly rare. To quote more directly:

"On the whole, I may say that the workmen are a healthy set of men. They do not suffer from any definite diseases, as do the workers in lead, arsenic, and mercury.

"One very remarkable circumstance (of which I was first informed last year by Benham and Froude, Chandos street) was mentioned at each of the works, viz, the absolute freedom of the workmen from cholera or even choleraic diarrhea. During each of the great cholera outbreaks there were terrible ravages in one or other of their neighborhoods, but not one of these men was in the slightest degree affected.

"At all events, the immunity of this class of men from cholera is a remarkable and positive fact. I have for a long time made many inquiries in this matter, and can not as yet learn that a single case has occurred amongst them.

"It seems to me, therefore, that in seasons of cholera some form of taking it in small quantities as a prophylactic might be devised with the utmost benefit—perhaps the sulphate of copper; it is not in any way injurious, even if it should do no good. Doctor Elliotson related the case of a patient who had taken sulphate of copper daily for three years, for a particular complaint, without its having produced any constitutional effect.

"How is it that the effect of copper, even when inhaled for years, is comparatively so slight, and does not lead on to any special diseases? Probably, as I think, because the system can tolerate an excess of what is a natural constituent, however minute in quantity, infinitely better than it can the introduction of what is entirely foreign, such as lead, arsenic, and mercury; and in my opinion it has been clearly shown that copper is a natural constituent."

---

[a] Edward Clapton, Clinical Society of London, Transactions, **3**:7 (1870).

CONCLUSION.

Experience has demonstrated the practical value of copper sulphate as an agent for the purification of contaminated water, and it is believed that most of the important conditions likely to obtain have been encountered and successfully dealt with. Unsuspected features may arise, however, and more complete information on the influence of the chemical constitution and temperature of the water and on the recurrence of polluting organisms is very much to be desired. It is therefore urged that water engineers, sanitary engineers, and others who may be interested keep accurate records of treatments made and report any unusual cases that may present themselves.

SUMMARY.

During the summer of 1904 over 50 reservoirs were successfully treated for the removal of algæ. From these results and from further experiments in the laboratory and elsewhere the following facts have been developed:

Much less copper is required to eradicate algæ from reservoirs than would be necessary to destroy algæ under laboratory conditions.

The effect of this metal upon fish is of considerable importance and requires more study.

The physical and chemical constitution of a water are factors to be considered in determining the quantity of copper sulphate to use in a water supply.

The elimination of polluting forms sometimes makes possible the development of other species, but so far these species have never been the cause of complaint.

As a result of the sudden destruction of great numbers of polluting algæ for a few days immediately after treatment of a water supply there is sometimes an increase in odor and taste.

The use of copper is an efficient emergency method for sterilizing water contaminated with the bacillus of typhoid fever.

Metallic copper offers a convenient and efficient means of sterilizing small amounts of water.

Copper may be useful in the proper disposal of sewage.

Copper is of great value as a supplement to filtration in case of accident or mismanagement.

Under certain conditions copper may be used to great advantage in connection with filtration.

There is no authentic record of fatal copper poisoning, and many of the best authorities do not consider copper a true poison; they hold that it is a natural constituent of the body, and in minute quantities has no effect upon man.

The suggested medicinal use of copper in cholera, typhoid, and related diseases seems important.

AVOCADO TREE, FREEHOLD, COSTA RICA.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 77.

B. T. GALLOWAY, *Chief of Bureau.*

THE AVOCADO,

A SALAD FRUIT FROM THE TROPICS.

BY

G. N. COLLINS,

Assistant Botanist in Investigations in
Tropical Agriculture.

BOTANICAL INVESTIGATIONS AND EXPERIMENTS.

Issued July 5, 1905.

239388
13.1.30

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

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Pathologist and Physiologist, and Chief of Bureau.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., December 3, 1904.

Sir: I have the honor to transmit herewith the manuscript of a technical paper entitled "The Avocado, a Salad Fruit from the Tropics," and to recommend its publication as Bulletin No. 77 of the series of this Bureau. This paper was prepared by Mr. G. N. Collins, Assistant Botanist in Investigations in Tropical Agriculture, and has been submitted by the Botanist with a view to publication.

The eight half-tone illustrations are considered necessary to a complete understanding of the text of this bulletin.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The avocado is a tree native in Central and South America, where it has been cultivated by the aborigines since very ancient times. The large and usually pear-shaped fruit is not used as a fruit in the popular sense of that word, but as a salad. It is highly prized by those familiar with it in the American Tropics, and as its nature comes to be more widely understood in the United States its popularity increases. There is now a regular demand for it in our large cities. The long journey which the avocado must make between producer and northern consumer renders important the question of shipping qualities. But one type is known in Porto Rico, and this will not withstand shipment to New York except in cold storage.

While accompanying Mr. O. F. Cook, of this Department, on expeditions to Mexico, Central America, and the West Indies for the study of coffee, rubber, and other tropical cultures, Mr. Collins has found that the varieties of the avocado are much more numerous and diverse than was hitherto supposed. In developing the culture of avocados it is important that these varieties be canvassed to secure the best types. Of particular interest are the remarkably thick-skinned avocados of Guatemala, which thus far appear to have escaped notice. These varieties promise to withstand shipment much better than any of the thin-skinned forms now cultivated, and their introduction into Porto Rico will, it is hoped, aid materially in establishing a profitable industry in that island.

Mr. Collins's report contains much information, acquired under his exceptionally favorable opportunities for observing the avocado, which will be useful to those interested in the culture, transportation, and marketing of this salad fruit.

FREDERICK V. COVILLE,
Botanist.

OFFICE OF BOTANICAL INVESTIGATIONS AND EXPERIMENTS,
Washington, D. C., September 30, 1904.

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THE AVOCADO, A SALAD FRUIT FROM THE TROPICS.

INTRODUCTION.

As our contact with the Tropics becomes more and more intimate, and transportation facilities are improved, the number of fresh food products received from tropical countries is rapidly increasing. Among the most promising of such articles is the avocado, still little known, but rapidly increasing in favor.

The avocado, though technically a fruit and usually referred to as such, is from the culinary standpoint no more a fruit than the cucumber. It is more accurately described by the term "salad fruit," and may be said to stand alone as the only fruit that when ripe is eaten almost exclusively as a salad. The nearest approach to this is perhaps the olive, which is eaten more as a relish. This unexpected rôle no doubt accounts to a large extent for the dislike or indifference often professed by persons tasting the avocado for the first time. As in the case of the olive, where the novice usually describes the fruit as an insipid pickle, the appearance of the avocado leads one to expect a sweet or acid fruit, and the more or less unconscious disappointment usually leads the experimenter to pronounce the avocado tasteless and oily. One writer describes it as having a "taste not much like that of our pears [the avocado is often called 'alligator pear'], and in first trying to eat the fruit one may pronounce it a poor pear but a good kind of pumpkin," and adds the charitable suggestion that "cooking or preserving may bring out the hidden virtues."

Few persons who live for any length of time in countries where avocados are to be had fail to acquire a taste for this delicious salad fruit. It is the rule, however, that the taste for an entirely new article of diet has to be cultivated, and a food which was unknown to our fathers and which we meet for the first time after our tastes have been formed is seldom accepted at the first trial. In most cases it is only after repeated attempts, prompted usually by the assurances of the initiated, that a fondness for the strange article begins to grow. The human taste is, however, fairly uniform, and a liking for any food that is popular in its native country is usually acquired by the stranger if his first attempts do not create a prejudice so strong as to prevent further experiments. As examples of foods that when first tried outside of their native country were by most people either disliked or considered insipid but which have since become firmly established may be mentioned olives, bananas, artichokes, chocolate, tomatoes, curries, and peppers.

With avocados the taste is usually acquired after two or three attempts, and many profess a fondness for the fruit at the first trial. That the taste when once acquired amounts almost to a craving is attested by prices paid for the fruit in the northern markets, where 15 cents each is about the lowest figure at which they can be bought, and good fruit usually sells as high as 30 cents, though 50 or 60 cents is not an uncommon price. The avocado may thus be said to have taken the first steps along the lines by which most foreign fruits have been successfully introduced.

An early impetus was received when the fruit was served on the tables of the rich and fashionable, its intrinsic merit being aided, without doubt, by the desire to inaugurate a novelty at once rare and expensive. The tendency to imitate this use assisted in increasing the demand until the fashionable hotels were able to score a point by adding the fruit to their menus. From this stage to that of introduction into the markets and fruit stores, where the general public will make its acquaintance, is, perhaps, the slowest and most crucial step in the history of a successful new product, and one that the avocado is at present undergoing.

ORIGIN AND HISTORY.

EARLY ACCOUNTS.

What appears to be the earliest reference to the avocado is found in Oviedo's report to Charles V of Spain, in the year 1526,[a] a translation of which follows:

> On the mainland are certain trees that are called pear trees (perales). They are not pear trees like those of Spain, but are held in no less esteem; rather does this fruit have many advantages over the pears of that country. These are certain large trees, with long narrow leaves similar to the laurel, but larger and more green. This tree produces certain pears, many of which weigh more than a pound, and some less; but usually a pound, a little more or less, and the color and shape is that of true pears, and the skin is somewhat thicker, but softer, and in the middle it holds a seed like a peeled chestnut; but it is very bitter, as was said farther back of the mammee, except that here it is of one piece and in the mammee of three, but it is similarly bitter and of the same form; and over this seed is a delicate membrane, and between it and the primary

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[a] Sumario de la Natural Historia de las Indias. (Biblioteca de Autores Españoles, Historiadores Primitivos de Indias, Madrid, 1852. 1:502.)

skin is that which is eaten, which is something of a liquid or paste that is very similar to butter and a very good food and of good flavor, and such that those that can have them guard and appreciate them; and they are wild trees in the manner that all those that have been spoken of, for the chief gardener is God, and the Indians apply no work whatever to these trees. With cheese these pears taste very well, and they are gathered early, before they are ripe, and stored; and after they are collected they mature and become in perfect condition to be eaten; but after they are ready to be eaten they spoil if they are left and allowed to pass that time.

A more complete discussion appears in the same author's History of the Indies,[a] written some time after his original report, where he adds that some years after his report to Charles V "I saw many of these pear trees in the province of Nicaragua, placed by hand in the lands and yards or gardens of the Indians and cultivated by them. And some of these trees are as large as walnut trees, but the pears are smaller than those of Cueva." The locality referred to in his first account is the northern part of Colombia, near the Isthmus of Panama. The fruit described would seem to resemble some of the poorer varieties common in southern Mexico, or the Costa Rican fruit known as "yas," referred to *Persea frigida* Linden. (See Pl. VIII.) The fruit must have been of good size and the seed very large, for without knowing the size of the "vinous pears of Spain," to which the fruit is compared, the weight is said to be about a pound, while the flesh is said to be the thickness of a goose quill.

Cieza de Leon[b] refers to the avocado as one of the native fruits eaten by the Spaniards of Panama (p. 16), and as one of the foods of the natives of Arma and Cali, Colombia (pp. 72–99). It would seem that the fruit was of considerable importance, as it is one of the very few kinds of which particular mention is made. The fruit described is said to have the pulp about the thickness of a finger.

Hernandez[c] describes the avocado in Mexico under the Aztec name "ahuacaquahuitl." There is also a long description of both the fruit and the tree in Ulloa's Voyage to South America (1736).

The first authentic reference thus far found to the avocado in the West Indies is made by Hughes.[d]

COMMON NAMES.

The various common names of the avocado form a curious and undignified jumble. None seems to be available that is not either misleading in its application or difficult to pronounce.

The most common designation among English-speaking people is

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[a] Oviedo, 1851, Historia General y Natural de las Indias, 1: 353.

[b] The Travels of Pedro de Cieza de Leon [1532–1550]. Hakluyt Society, 1864.

[c] Hernandez, F., 1651, Rerum Medic. Nov. Hisp. Thes., 89.

[d] Hughes, W., 1672, The American Physitian, 40.

"alligator pear," and, although it is very difficult and for many reasons undesirable to change a popular name, it seems best while this fruit is still little known to endeavor to secure a less misleading designation. The name "avocado" is almost as widely used as "alligator pear," and, while not altogether unobjectionable, its adoption will avoid the confusion of this salad fruit with varieties of the common pear. The use of the name "alligator pear" not only retards the true appreciation of this very distinct article of diet, but will eventually cause annoying complications in statistical classifications of the products of regions where both this and true pears are grown. The word "pear" is sometimes appended to "avocado," and the name is then no less objectionable than the other form.

"Palta" is applied to the avocado in Chile, Peru, and Ecuador, and is said by Garcilasso de la Vega [a] to have been applied by the Incas, who brought this fruit from the province of that name to the warm valley of Cuzco, although it seems not improbable that the province may have received its name from the tree, according to the common custom of primitive people.

The name "ahuacaquahuitl," given by Hernandez, signifies "like the oak tree," and is variously spelled by other writers.

The words "aguacate" and "avocado" are probably Spanish spellings of attempts to pronounce the Aztec name. To an Andalusian the sound of the word would naturally suggest the spelling "aguacate," while a Castilian would be more likely to adopt the other form.

The French name "avocat" is probably a modification of the Spanish, or perhaps an independent approximation of the native name.

The tendency to transform a new name into a word already existing in the language is shown in the spelling "abogado" in the Spanish and "avocat" in the French, both words meaning lawyer.

Tussac [b] gives "aoucate" as the Carib name and derives the French "avocat" from that form. Jumelle and Pickering also give modifications of this word as Carib. It seems impossible that the Carib and Aztec names should be so similar, and it is more likely that the Carib's attempt to pronounce the Spanish designation was erroneously recorded as a native name.

The form of the fruit obviously suggests the term "pear," and "perales," or pear trees, was the name under which they were first recorded by Oviedo in 1526, that author, however, stating that they were pears in form and in nothing else.

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[a] Garcilasso de la Vega, Ynca, 1605, Royal Commentaries of the Yncas, Hakluyt, ed., 2:335.

[b] Tussac, F. R. de, 1824, Flore des Antilles, 3:15.

The name "alligator" is entirely without warrant, and no one has as yet suggested even a fanciful application to any of the characteristics of the fruit or tree. It has been suggested that the term is a further corruption of the Spanish "aguacate," and this must be admitted as possible. The occurrence of the word "alligator" prefixed to the names of plants, such as "alligator pepper" for *Amomum melegueta* Rosc., suggests that the word may formerly have been used to signify false or worthless, and if this were true its application to this pear-shaped fruit would be very natural.[a]

The application of other English names, such as "subaltern's butter," "midshipman's butter," "vegetable marrow," etc., is obvious.

Below is a partial list of the names and spellings that have been applied by different writers:

Popular names of the avocado.

Name.	Country.	Language.	Authority.
Abacate	Brazil	English	Orton, p. 5.
Aguacate		Spanish	
Aguacatillo	Mexico		Ramirez, p. 3.
Agualate		Spanish	Velasquez Dict.
Ahoacaquahuitl	Mexico		Ramirez, p. 3.
Ahuaca	do	Aztec	Jumelle, p. 179.
Ahuacahuitl		do	Markham, in Cieza de Leon p. 16.
Ahuacalt		do	Sagot, p. 196.
Ahuacaquahuitl	Mexico	do	Hernandez, p. 89.
Ahuacate	Peru	Spanish	Velasco, I, p. 63.
Albecato pear	Jamaica	English	Sloane, II, p. 133.
Alligator pear		do	
Aouaca		Carib	Jumelle, p. 179.
Aouacate	Antilles	do	Tussac, p. 15.
Avicato		English	Knox, p. 222.
Avigato	Barbados	do	Hughes, G., p. 130.
Avoca	Mauritius		Lequat, II, p. 201.
Avocado		Spanish and English	
Avocadobirne		German	Semler, II, p. 454.
Avocado pear	British West Indies.	English	Bois, Rev. Hort., 1900, p. 546
Avocat		French	Jumelle, p. 179.
Avocato			P. Brown, p. 214.
Avogato pear		English	Dampier, p. 203.
Butter pear		do	
Cupanda	Tabasco, Mexico		Ramirez, p. 21.
Cupandra	Mexico		Do.
Cura	South America		Amador, in Oviedo, p. 353.
Custard apple	West Africa	English	
Laurell peach			Parkinson, p. 1514.
Mantequilla silvestre	Mexico	Spanish	Semler, IV, p. 264.
Midshipman's butter		English	Smith, Treasury of Botany.
Nicaraguae pomum		Latin	Chambrey, p. 586.
On	Yucatan	Maya	Ramirez, p. 138.
Palta	Peru		Cieza de Leon, p. 73.
Patta	Peru and Mexico		Lunan, p. 38.
Peral de abogado		Spanish	Jacquin, p. 38.
Peras	Colombia	do	Oviedo, p. 353.
Sabaca			Lunan, p. 38.
Shell pear	Jamaica	English	Hughes, W., p. 40.
Spanish pear	do	do	Do.
Subaltern's butter			Marayat.
Tonalahuate	Morelos, Mexico		Ramirez, p. 70.
Vegetable marrow		English	Smith, Treasury of Botany

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[a] Other instances of the use of this word that admit of this interpretation are alligator apple (*Anona palustris* L.) and alligator crocodile (*Ostcolacmus tetraspes*). The word "alligator" is said to be derived from the Spanish *El Lagarto,* meaning "the lizard." The expression "alligator tears" or "crocodile tears" can also be interpreted in the same way.

NOT NATIVE IN THE WEST INDIES.

Many general works on tropical agriculture refer to the avocado as a native of the West Indies. There seems, however, to be no positive warrant for this, while there are many indications to the contrary. De Candolle [a] states that it has been found wild in this region, but the authority cited [b] says simply "American Tropics," and his records of the different varieties occurring in the West Indies evidently refer to cultivated forms. A wild species of Persea, *P. sylvestris*, is reported from Cuba, but this is quite distinct from the avocado, and is called by the Cubans "aguacate silvestre." The statement "in insula S. Dominici" occurs in Bauhin's description of the avocado.[c] Acosta is cited, however, and this author gives no reference to the fruit in that locality.

The avocado was certainly not common nor was it cultivated in the West Indies before the time of Columbus, for of the early writers consulted none makes mention of it as native in that locality, although references to it in Colombia, Ecuador, and Peru are frequent. It is significant that Oviedo entitles his discussion "De los perales salvajes de la Tierra-Firma," or "Wild pear trees of the mainland," and does not mention their occurrence on the islands, as he does in the case of so many other plants. This part of his history was apparently written while in Santo Domingo, and his knowledge of that island is so circumstantial as to make it very improbable that he could have remained ignorant of its existence there, and while less conversant with the remainder of the West Indies he makes mention of many comparatively obscure plants as existing in "other islands;" all of which seems to indicate that the avocado was unknown in the Spanish settlements of the West Indies in the early part of the sixteenth century.

Hughes,[d] Dampier,[e] and Hans Sloane [f] refer to the avocado as planted in Jamaica by the Spaniards. Brown [g] definitely states that the tree was introduced into Jamaica, and Jacquin [h] says the same of the West Indies as a whole. Tussac [i] also affirms that the avocado is not a native of the West Indies, although he gives a Carib name for the plant.

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[a] De Candolle, 1885, Origin of Cultivated Plants, 292.

[b] Meissner, 1864, in De Candolle, Prodromus, 15 : 1 : 53.

[c] Bauhin, Caspar, 1623, Theatri Botanici, 439.

[d] Hughes, W., 1672, The American Physitian, 41.

[e] Dampier, William, 1703, A New Voyage Around the World, 1 : 202.

[f] Sloane, Hans, 1725, Natural History of Jamaica, 2 : 133.

[g] Brown, P., 1789, History of Jamaica, 214.

[h] Jacquin, J. N., 1764, Observ. Botanic, 1 : 38.

[i] Tussac, F. R. de, 1824, Flore des Antilles, 3 : 15.

DISTRIBUTION.

The avocado has, since the time of Columbus, spread from its home in America entirely around the Tropics. That such an important food plant was confined to the American continent until the post-Columbian contact with the Old World, while numerous other plants, such as the yam, taro, and sweet potato, had already spread to parts of the Old World, was probably due to the fact that the avocado will not easily survive long voyages, while most of the tropical root crops have much greater vitality.

The fruit spread but slowly before the last century, but in recent times its culture has rapidly increased, and it is now cultivated in most of the countries that are suited to its growth. It has been cultivated in India since about 1860, and has reached the islands of Madagascar, Reunion, Madeira, the Canaries, Samoa, and Tahiti. In Natal and Australia it is just gaining a foothold. Its cultivation is increasing in Algiers. In 1882 it was reported as growing in southern France along the shores of the Mediterranean. Some of the trees had flowered, but apparently none had fruited at that time. In southern Spain, however, the tree fruits, and is cultivated to a limited extent.

E. Roul [a] gives the range of this species as 36° from the equator. He states, however, that certain varieties, such as "dulce," are not found outside the Tropics.

The avocado seems to have commanded very little attention in the West Indies. No mention is made of this fruit in Morris's account of the British West Indies, and the index to the bulletins of the botanical department of Jamaica does not contain a single reference to it. In Porto Rico the fruit is abundant and popular, although not so important a staple as in tropical Mexico, where quantities of even the most inferior fruit are consumed by the natives, who consider it an important ingredient of that indispensable Spanish dish, soup.

There are now orchards of avocados in southern Florida and California, and a slightly hardier variety would greatly extend the culture of this fruit in these regions.

Cuban fruit is shipped to the northern markets, and the conditions in that island are probably similar to those existing in Porto Rico.

In the tropical parts of Mexico, Central America, and South America the fruit is very common, and its different forms and races are innumerable.

DESCRIPTION.

The avocado tree is 20 to 60 feet high, varying in habit from tall and rather strict to short and spreading. In favorable situations the top is very dense. The leaves are 20 to 40 cm. long and 7 to 25 cm. wide, acuminate at the apex, varying from acute to truncate at base, petiole 2 to 8 cm. long. The upper surface is smooth, with depressed veins; the lower surface is glaucous, with the raised veins slightly pubescent. Different forms, all referred to the one species, vary so greatly in the form and size of the leaves that close relationship would hardly be suspected. Climatic differences may possibly account for some of this variation, the large, broad-leaved forms being usually found near the coast. Young trees have also, as a rule, much larger leaves.

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[a] Sagot, P., Manuel Pratique des Cultures Tropicales, 198, 1893.

The flowers are perfect and are borne on loose axillary racemes near the ends of the branches, usually at the base of the year's growth. The corolla is wanting, the calyx 6-parted. The lobes are all of equal length, green in color, and pubescent. The stamens are 9, in three series; the anthers 4-celled, opening by valves hinged distally. The two outer series have the openings introrsely directed; the inner series has the two distal valves introrsely, the basal pair extrorsely, directed. Each stamen of the inner series bears near its base two large glands. Inside the stamens are three staminoidia. Occasionally 4-parted flowers are to be found, in which case they are 4-parted throughout. The ovary is 1-celled, the style simple.

The fruit in some varieties is long and slender; in others, nearly globular, varying from 3 to 15 cm. (1 to 6 inches) in diameter. The outside covering in some forms is soft and pliable, often less than one-half millimeter in thickness, while in others it is hard and granular, in some of the Central American forms reaching 3 mm. in thickness. The fleshy part of the fruit between the skin and the seed varies greatly in thickness, but is always butyraceous in consistency, though in some cases much firmer than in others. In the better varieties the fibrovascular system that enters the fruit from the stem is discernible only in the thin flesh at the very base of the fruit and at the base of the seed, which is toward the apical end of the fruit. The seed thus appears to receive its nourishment directly from the pulp by absorption or ceases to receive nourishment before the fruit is fully formed. In the coarser forms the bundles can be traced from the stem throughout the pulp to the point where they enter the seed, and in some cases they are so prominent that the quality of the fruit is seriously impaired.

The tree is usually described as evergreen. In some localities, however, the leaves are dropped just before flowering, leaving the tree naked for a short time. This is the case in Alta Vera Paz, Guatemala, where a type with narrow leaves and very thick-skinned fruit prevails. Whether this deciduous character is peculiar to the variety or the result of climatic conditions could not be determined.

The seed is single, inverted, exalbuminous, spherical, or pointed, provided with two more or less distinct coats, one or both of which may adhere very closely to the cotyledons, though usually separable at the base of the seed; or they may adhere to the flesh of the fruit and separate from the cotyledons. This latter condition is observed more commonly in specimens not fully matured. The surface of the outer coverings may be coarsely reticulated or granular. The seed coats are frequently produced into a point beyond the apex of the cotyledons. The cotyledons are nearly hemispherical in form, white or light green in color. The surface of some forms is smooth; in others rugose. The plumule is well developed before the fruit ripens and is located from 10 to 15 mm. from base of seed. Concerning the seedling, Holm[a] has pointed out that no hypocotyl develops. He also calls attention to the curious fact that the first four leaves are opposite and by showing a differentiation into petiole and blade more closely resemble the mature leaf than do the following five or six leaves, which are almost scalelike.

BOTANICAL AFFINITIES.

The genus Persea, to which the avocado belongs, is a member of the family Lauraceæ. Among the other more important economic members of the family are cinnamon (*Cinnamomum cinnamomum* (L.) Cockerell), camphor (*Cinnamomum camphora* (L.) Nees), and sassafras (*Sassafras sassafras* (L.) Karst.). With the exception of cinnamon, they are used chiefly in medicine. The avocado is the only member of the family cultivated for its edible fruit.

Mez, in his monograph of the family,[b] describes forty-seven species of Persea, and states that the genus is confined to the American continent, with the exception of one species in the Canary Islands.

On the contrary, F. Pax[c] restricts the genus to ten species, only one of which, *P. persea* (L.) Cockerell (*P. gratissima* of Pax), belongs in America. No intimation is given as to the disposition of the other American species. This latter author divides the genus into two sections—Eupersea, with the one species *P. persea*, and Alseodaphne, with nine Old World species, five of which are imperfectly known.

It is almost impossible to come to any satisfactory conclusion in regard to the systematic relationships of the various forms of avocados, for the present classification of this group is based almost entirely on floral and foliage characters, and in most cases it is impossible to secure flowers or leaves from the individual trees which produced the different fruits. This is especially the case with fruits collected in the markets, but even where the fruit is collected from the trees no flowers will be present at the time the fruit is mature, and complete material can only be secured by residents or by repeated visits to the same locality at different seasons.

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[a] Bot. Gaz., July, 1899, p. 60.

[b] Mez, Carolus, 1889, Lauraceæ Americanæ, Jahrb., Königl.-bot. Gart., 5: 135.

[c] Engler and Prantl. Die Natürlichen Pflanzenfamilien. 1889. 3: 2: 114–115.

On the other hand, out of the forty-seven species described by Mez twenty-six have the fruit unknown, and in the two varieties distinguished from the typical *P. persea* no mention is made of the fruit.

The diagnostic characters of the species as shown in this author's key to species are:

> Anthers of the three outer series fertile, 4-locellate; ovary pilose; perianth-lobes equal or subequal; filaments two and one-half to three times as long as the anthers; staminodes twice as long as the stipe.

With regard to leaf characters, it is difficult to draw definite conclusions, as the characters of the leaves vary greatly at different stages of the tree's development.

VARIETIES.

The botanical descriptions of varieties of the avocado are in nearly every case too meager and too general in their terms to be recognized and are in every case based on floral and leaf characters, no mention being made of the fruit. Meissner[a] describes four varieties, as follows:

> Var. *vulgaris.* Leaves medium sized, mostly 3 to 4 inches long, 1½ inches broad, oval or obovate; flowers short pediceled. West Indies, Central and South America.
>
> Var. *oblonga.* Leaves long, equally attenuate at both ends, often acute, 4 to 9 inches long, 1¼ to 2 inches wide, short pediceled. West Indies, Mexico, Peru, Brazil, Mascarene Islands, Java.
>
> Var. *macrophylla.* Leaves larger, 6 to 9 inches long, 3 to 4½ inches broad, obovate or obovate-oblong, acutely acuminate, short pediciled. Eastern Peru, British Guiana, Central America, Mexico.
>
> Var. *schiedeana.* Leaves ample, 9 inches and over in length, 3 to 4½ inches broad, obovate and oblong, acute or obtuse, young leaves with a thick yellow tomentum, veins and veinules rather accentuated underneath, panicles terminal, bases with long persistent imbricate bracts, pedicels rather long. Misantla, Mexico.

Mez[b] recognizes two varieties as differing from the normal type, one of which is the *schiedeana* described above and which is apparently confined to Mexico; the other, *drimyfolia*, also confined to

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[a] Meissner, in De Candolle, Prodromus, 15:1:53.

[b] Mez, Carolus, 1889, Lauraceæ Americanæ, Jahrb., Königl.-bot. Gart., 5:147.

Mexico, was formerly considered a distinct species. A translation of his description of the latter variety is as follows:

Variety *drimyfolia.*

> Differs from the normal form in being smoother; leaves oblong lanceolate, narrowly acute at base, apex acute or somewhat acute, below glaucous.
>
> A delicious fruit tree, cultivated in tropical regions, and from thence imported into Europe. In Portugal and Sicily it winters if protected, and sometimes produces mature fruit. Embryo (according to Schomburgk) often with 3 cotyledons, and frequently germinating on the tree. According to Krug, the fruits of this tree come true to seed, and it is not necessary to graft.

This description applies best to the hard-skinned types of Guatemala, the peculiarities of the fruit of which seem never to have found their way into literature, and it is probable that the similarity is confined merely to the dimensions of the leaves.

The marked differences in the fruits of the avocados from different localities are recognizable in the earliest descriptions. Hernandez's description of a black fruit the size and shape of an egg or fig corresponds well with many of the small black forms grown in Mexico at the present time and, so far as known, not occurring elsewhere. On the other hand, all the early writers on the West Indies describe a much larger fruit with much thicker flesh.

The distinction between the thick-skinned and thin-skinned forms of the avocados was made as early as 1590 by Acosta,[a] who wrote:

> The Palta is a great tree, and carries a faire leafe, which hath a fruite like to great peares: within it hath a great stone, and all the rest is soft meate, so as when they are full ripe, they are, as it were, butter, and have a delicate taste. In Peru the Paltas are great, and have a very hard skale, which may be taken off whole. The fruite is most usual in Mexico, having a thinne skinne, which may be peeled like an apple: they hold it for a holesome meate, and, as I have said, it declines a little from heat.

It is worthy of note that the earliest account of the avocado in the West Indies, by Hughes,[b] describes a hard-skinned type, yet so far as known this type does not exist in the West Indies at the present time. The description referred to follows:

> This is a reasonable high and well-spread Tree, whose leaves are smooth, and of a pale green colour: the Fruit is of the fashion of a Fig, but very smooth on the outside, and as big in bulk as a Slipper-Pear; of a brown colour, having a stone in the middle as big as an Apricock, but round, hard and smooth; the outer paring or rinde is, as it were, a kinde of a shell, almost like an Acorn-shell, but not altogether so tough; yet the middle substance (I mean between the stone and the paring, or outer crusty rinde) is very soft and tender, almost as soft as the pulp of a Pippin not over-roasted.
>
> It groweth in divers places in Jamaica; and the truth is, I never saw it elsewhere: but it is possible it may be in other Islands adjacent, which are not much different in Latitude.

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[a] History of the Indies, Hakluyt Society ed., 1: 250.

[b] Hughes, W., 1672, The American Physitian, 40–42.

I never heard it called by any other name then the Spanish Pear, or by some the Shell-Pear; and I suppose it is so called only by the English (knowing no other name for it) because it was there planted by Spaniards before our Countrymen had any being there; or else because it hath a kinde of shell or crusty out-side.

I think it to be one of the most rare and most pleasant Fruits in that Island: it nourisheth and strengtheneth the body, corroborating the vital spirits, and procuring lust exceedingly: the Pulp being taken out and macerated in some convenient thing, and eaten with a little Vinegar and Pepper, or several other ways, is very delicious meat.

GEOGRAPHICAL TYPES.

In nearly all parts of the American Tropics there is great variety in the forms of the avocado, yet comparatively few have received distinctive names, and only a very few have found their way into literature. In the Revue Horticole, 1900, page 546, D. Bois describes nine Mexican varieties as follows:

Dulce largo, green, in form of a gourd, with a long neck; seed large.
De tecosautla, dark green, with ovoid seed.
Pagua, large, spherical, purple in color, with a large seed.
Morado de Chalco, pear-shaped, purplish.
Dulce, large, green, oblong, with whitish, ovoid seed.
Pagua redonda, round, green, with a very large reddish seed.
Verde de San Angel, light purplish, pear-shaped.
Morado de San Angel, light purple; seed ovoid.
Verde chico, small, green, with an elliptical seed.

These same varieties appear in slightly different form in Sagot's Manuel Pratique des Cultures Tropicales, page 157.

Sagra[a] mentions four forms from Cuba, as follows:

Violet, almost round.
Thick green, round, with yellowish flesh of a spongy consistency.
Long yellow, similar to a large pear.
Long green.

There is little to be gained in attempting to identify these forms, as none of the characteristics of economic importance are mentioned, and from observations made in Mexico it appears probable that these forms merge into one another with many imperceptible gradations.

The author has had the opportunity of studying avocados in Porto Rico, Guatemala, Costa Rica, and Mexico; and from the fruit that has come under observation the avocados of Mexico, while diverse in form and color, seem to be much more closely related to each other than to those of any other of the above-mentioned countries.

As much of the fruit was obtained in markets, it was often impossible to determine the character of the tree on which any particular fruit was borne, and in no case could floral and fruit characters be compared. Aside from yield, vigor, and hardiness, however, the more important characteristics of a variety, from a commercial standpoint, can be determined from the fruit alone.

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[a] Sagra, Ramon de la, Historia Fisica Politica y Natural de la Isla de Cuba, 11: 186, 1863.

In a general way each of the countries visited exhibited distinct types of avocados, although in nearly every case aberrant forms occur which frequently seem to be associated with the types of other countries. In many such cases the resemblance is probably a similarity in formal characters rather than a true relationship.

In making the following descriptions, several new characters have been used, such as the nature of the skin, whether it is hard or soft, thick or thin, and the character of the seed coats, believing that these are of more importance than the form and color by which the cultivated varieties have usually been distinguished.

Until more complete botanical studies have been made it seems advisable in describing the different forms to take them up by countries. The names applied to the different forms are merely to facilitate reference. It seems a curious fact that although the avocado has a great variety of names in different countries the different forms in any particular locality rarely receive distinctive appellations. Thus in Porto Rico, where mangoes that to the casual observer appear identical are carefully distinguished and provided with particular names, the many varied forms of avocados are all called "aguacate" without further distinction. In Mexico also, where the variety is still greater, no names for the different forms could be elicited from those selling the fruits in the markets, although the qualities of the different forms were keenly appreciated and willingly pointed out.

As might be expected, there are several countries that claim to produce the finest avocados, among which may be mentioned Colombia, Hawaii, Peru, and Brazil. According to travelers familiar with the Pacific coast of tropical America, the largest and finest avocados come from the vicinity of Tamaco, in Colombia. These are said to be much larger than those of the Central American coast and of equally fine flavor.

In Brazil the finest fruits are said to come from the islands of Marajo, at the mouth of the Amazon.

As with most fruits, the largest and fairest are not always the best flavored. The delicate nutty flavor of some of the small thin-fleshed kinds of Guatemala is seldom equaled in the large thick-fleshed varieties.

GUATEMALA.

The avocados of Guatemala form a very distinct group. They are at once the most marked and, from a commercial standpoint, the most promising type for introduction into our tropical possessions.

The most peculiar characteristic of the Guatemalan avocados is the unusual texture of the skin. Unlike the Mexican and West Indian types, which are those usually found in our northern markets, the Guatemalan fruit is covered with a skin so thick and unyielding that it suggests the shell of a nut. If pressed inward with the finger, instead of bending or tearing, the skin breaks with a granular fracture.

To judge from Acosta's account, the avocados of Peru have a skin similar to those in Guatemala, though, curiously enough, in Costa Rica, midway between these two countries, not a single hard-skinned form was observed. In all the Guatemalan varieties the seed coats adhere closely to each other and to the cotyledons over nearly the entire surface. In this respect they resemble the Mexican and differ from the Cuban and Porto Rican forms, which have the seed coats distinct from each other, the outer coat usually adhering to the flesh. The flesh of the Guatemalan forms frequently contains objectionable fibers, but in many cases it is entirely fiberless. In every case the line of division between the flesh and the skin is distinct, and the flesh can be scooped out with a spoon and the skin scraped, agreeing in this regard with the Cuban forms and differing from those of Mexico and Porto Rico, where there is no marked line between the flesh and the skin, and where, if care be not taken in using the spoon, portions of the skin are taken up with the flesh. Fruit of this type is borne on the tall, spreading trees common in Guatemala. The leaves are narrower and longer than in the West Indian type, about 23 cm. (including the petiole, which is about 2.5 cm.) by 7.5 cm. wide, acuminate at the apex, tapering at the base. Leaves smooth above, with depressed veins; below, the veins are prominent, with numerous fine hairs, and the surface is glaucous, with scattered fine hairs.

Although in a general way belonging to one type, the avocados of Guatemala that came under the writer's observation can be separated into three forms capable of more or less definite delimitation.

Thick-skinned round (Pl. V).—This is the most common type in the eastern part of Guatemala. There is great diversity in size and quality among the specimens included under this form, and some of those found at Guatemala City appear to be distinct, but they are not easily separated by formal characters.

Form nearly spherical; color varying from dark green to dark brown or nearly black; skin hard and unyielding, breaking rather than tearing, never less than 2 mm. in thickness, granular in texture; flesh distinctly differentiated from the skin, often separated from it when fully ripe; seed as broad as or broader than long, rounded at the apex. The two seed coats are so united as to be indistinguishable, and when fully ripe adhere closely to the seed, except at a small area near the base. When the green fruit is opened the seed coats often leave the seed and adhere to the flesh.

The better specimens of this and the following form are probably the most promising for introduction into Porto Rico, owing to the thick skin, good keeping qualities, and fine flavor. In the warm and extremely moist climate of Alta Vera Paz, specimens of this form were in perfect condition two weeks after picking. Specimens sent by mail from Coban to Washington, while overripe on arrival, showed no outward evidence of decay, and were still in condition to withstand rough handling.

Thick-skinned oval (Pl. IV).—This description was drawn up to cover two specimens purchased at different times in the market of Guatemala City.

Form oval or oblong; surface roughened with knobs; skin thick and unyielding, breaking rather than tearing, granular in texture; flesh distinctly differentiated from the skin; seed longer than broad, rounded at the apex, covered when ripe with a mealy substance; coats adhering closely to the seed and separating from the flesh when ripe.

Soft-skinned Guatemalan.—Fruit pyriform; surface slightly roughened, shining, skin thick, soft, and yielding, tearing rather than breaking, distinct from the flesh; flesh free from fibers, firm, not darker near the skin. Seed almost spherical, with the outer coat produced into an acute point; seed coats closely united to each other and to the cotyledons except at the base and apex.

This form can hardly be considered a true Guatemalan type, as it lacks the characteristic hard skin. It resembles the Cuban type in many particulars, but differs from it in having the seed coats adhering closely to the cotyledons over the greater part of the surface and in having the outer seed coat produced beyond the apex of the cotyledons. It more nearly resembles the Costa Rican type.

In Guatemala there are at least two other species of Persea that yield edible fruit. These are known among the Indians of Alta Vera Paz by the names "coyo" and "coyocte." Both are generally considered very inferior fruits, though some prefer the "coyo" to the avocado. In Alta Vera Paz the "coyo" and the avocado flower at about the same time, but the fruit of the "coyo" ripens at least a month earlier, a fact which may lend interest to the species in efforts to extend the season.

In the highlands of central Guatemala the avocado is found in regions that are occasionally subjected to temperatures below freezing. The fruit is of good size and quality, and the thorough exploration of this region offers interesting possibilities in the securing of more hardy forms.

PORTO RICO.

The avocados of Porto Rico (Pl. II), although showing great diversity of form, are apparently very closely related, indicating possibly that they are the result of a single introduction. Compared with the types of the mainland thus far studied, their affinities seem to lie with Mexican avocados. From these they are distinguished chiefly by the character of the seed, the Porto Rican type having the two seed coats distinct, the outer usually adhering to the flesh, the inner more or less closely attached to the cotyledons. In this respect this type also differs from all the continental forms thus far observed. From the avocados of Costa Rica it is further distinguished by the texture of the skin, which is much thinner and softer than the Costa Rican type. In this latter regard it is still further separated from the Guatemalan avocados with their hard, almost brittle skins. From the Cuban type it is separated by the thinner skin and the fact that the flesh and skin are not sharply differentiated.

Form oval or pyriform, with or without a prolonged neck; color green, usually light; surface shining and almost smooth; skin thin and soft, tearing rather than breaking; flesh not differentiated from the skin; seed spherical, oval, or slightly pointed; the two seed coats entirely distinct, the outer usually clinging to the flesh and the inner to the cotyledons.

One specimen from San José, Costa Rica, seems to correspond closely with the Porto Rican forms, the only difference being a slightly thicker and more distinctly differentiated skin.

MEXICO.

The Mexican varieties show the greatest diversity of form, and also a considerable range of color. With the exception, however, of three special forms to be mentioned later, they seem to intergrade and form a connected series. They are at least much more closely related to each other than they are to those found in other countries.

Although many of the Mexican avocados were of really excellent flavor, none were seen that appeared particularly desirable for introduction.

The following is a general description covering the more characteristic features of the Mexican type:

Form spherical, oval, oblong, or pyriform; color varying from green to almost black; surface shining and almost smooth; skin thin and soft, tearing rather than breaking; flesh not differentiated from the skin; seed spherical, oval, or pointed; the two seed coats closely united and usually attached to the seed over the greater part of its surface.

Tapachula (Pl. III).—This sort was first observed at Tapachula, Chiapas, Mexico, where a single tree was found growing in the park. The same or a very similar variety was afterwards found in Costa Rica.

Form of fruit obovate or slightly pyriform; color bright green; surface shining and with slightly raised points white at the top; skin thin and leathery; flesh but imperfectly differentiated from the skin; seed nearly round. The tree rather short and spreading. The leaves broadly acuminate, almost transverse at base, the broadest part of the blade usually in the proximal portion.

This is apparently one of the most desirable of the thin-skinned sorts. Fully matured fruit was seen neither in Mexico nor in Costa Rica; consequently the character of the seed coats could not be determined. The Costa Rican specimens, while closely resembling the Mexican tree in the shape of the leaves and habit, as well as in the form and peculiar markings of the fruit, differ in having ovate seeds, while in the Mexican specimen the seeds are nearly round.

Long neck.—Of the two samples included in this description one is from Tapachula; the other was purchased in the Washington market and was probably from Cuba. The resemblance is doubtless confined to formal characters.

Form elongated, with a very long curved neck; color green; surface shining and somewhat wrinkled; skin soft, tearing rather than breaking; flesh distinctly differentiated from the skin; seed decidedly longer than broad, rounded at the apex; seed cavity extending into the neck beyond the apex of the seed; the two seed coats entirely distinct.

The flavor and texture of this form are very good, but it will probably not prove to be a good shipper.

Clingstone.—This most aberrant form was found only once in the City of Mexico. It is so very different from the ordinary avocados that it would seem that it must belong to a distinct species. Nothing was learned, however, concerning the nature of the tree, and the natives classed it with the other "aguacates."

Form elongated; color light green; skin soft and pliable, the surface somewhat shrunken and wrinkled; flesh granular in texture and almost tasteless, adhering closely to the seed; seed narrow and pointed; the two coats, if they exist, can not be separated.

The oddity of this form is its only recommendation.

COSTA RICA.

The avocados of Costa Rica show a greater diversity of color than those of any other country visited by the writer, ranging as they do from almost white to black through various shades of green, red, and purple. There is also a great variety of shapes. Still, with the exception of the "yas" (Pl. VIII),[a] they form a very connected series and are easily distinguished from those of other countries. As a group they may be characterized as follows:

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[a] In the Tropenpflanzer for September, 1903, C. Werckle refers this fruit to *Persea frigida* Linden, a name of doubtful validity. It is excluded from Mez's Lauraceæ Americanæ and placed among the species whose descriptions were unknown. The statement by Werckle that this species extends beyond the frost line makes it of possible importance for hybridizing, should it be desired to extend the culture of this fruit into subtropical regions.

Fruit spherical, pyriform, or gourd-shaped; color green, red, purple, or nearly black; skin rather thick, soft, distinct from the flesh. Seed spherical or with only the outer seed coat produced into a point; seed coats closely united to each other and to the cotyledons over almost the entire surface.

In the market at San José, Costa Rica, one specimen was found that could not be distinguished from the common Porto Rican type except that the skin was somewhat thicker than any observed in Porto Rico. A few samples of a form not elsewhere seen were also found in the same market. These were slender necked, with the seed cavity extending into the neck, the seed was oblong, the skin very thin and not distinct from the flesh, which was slightly darker near the skin. These specimens had a very fine flavor and would be desirable for local consumption; the thin skin, however, would probably prevent their being successfully shipped. Of the ordinary type none was seen that had marked desirable qualities.

CUBA.

The avocados of Cuba are closely related to those of Porto Rico, the principal differences being the thicker skin of the Cuban fruit and the fact that in the Cuban forms the skin is quite distinct from the flesh, which is not darker near the skin. The thicker skin may explain why Cuban fruit reaches New York in better condition than that of Porto Rico.

Fruit pyriform or nearly spherical; surface smooth and shining; skin thick, soft, and yielding, tearing instead of breaking, distinct from the flesh; flesh free from fibers, firm, not darker near the skin. Seed nearly spherical or pointed; seed coats entirely distinct from each other and from the cotyledons. Flavor poor.

Specimens on which this description was based were found in the Washington market and were said to have come from Cuba via New York. The flavor was very insipid, which may have resulted from the fruits having been picked when immature, or to overripeness.

HAWAII.

A series of specimens shipped from Honolulu to New York shows a soft-skinned fruit, in general like the avocados of Costa Rica, but much larger.

Form oval, oblong, or pyriform; color green or purple; nearly smooth, shining; skin soft, of varying thickness; flesh distinctly differentiated from the skin; seed longer than broad, variously shaped; the two seed coats usually united and adhering to the cotyledons, except at the base and apex.

A peculiarity not observed elsewhere is that of maturing several fruits in a cluster. In most countries all the fruits of a cluster, except one, drop when very small.

CULTURE.

The avocado was in all probability planted and more or less cared for by the natives of America before the advent of the Spaniards, for although Oviedo in his first account of the fruit in the northern part of Colombia says that the Indians apply no work to these trees, he later adds that "in the province of Nicaragua they are placed by hand in the gardens of the Indians and cultivated by them." Their culture, however, must have been of the crudest sort, limited probably to the mere planting of the seeds, perhaps of the more desirable kinds, near their houses and affording the young plants some slight protection. Nothing that corresponds to culture in the modern sense was applied to the avocado until the fruit was taken hold of by the planters of Florida.

PROPAGATION BY SEED.

The avocado tree is propagated almost entirely by means of seed, the uniformity of the fruit in many localities indicating that certain forms, at least, come true.

Like most tropical fruits, the seed of the avocado, if dried, will not retain its vitality for any length of time, and should be planted as soon as possible after it is removed from the fruit. If carefully packed so as to conserve the moisture, the seeds can, however, be kept alive long enough to permit of their being sent to any part of the world. A very successful method of accomplishing this is to pack them in slightly moistened charcoal placed in a closed receptacle, such as a wooden or tin box.

It is recommended that the avocado be planted where it is to remain, as the long taproot makes it difficult to transplant. If transplanted when small this will, however, be no great obstacle. The spacing will depend largely on the variety and the location, but should be from 15 to 30 feet.

ASEXUAL PROPAGATION.

The avocado is ordinarily considered a refractory subject for grafting or budding. Grafting is, indeed, seldom practiced, but the practicability of budding is now fully demonstrated. Rolfs[a] gives an account of the methods practiced in Florida, where the matter has received the most attention. The chief difficulty there is in causing the buds to start after they have taken. It may be that this difficulty is on account of unfavorable climatic conditions, for at the Hope Gardens, in Jamaica, Mr. T. J. Harris, under the direction of Hon. William Fawcett, has budded the avocado in large numbers with the loss of hardly a bud. The operation is successfully performed, not only by experienced hands, but students who are budding for the first time are quite as successful with the avocado as with the orange or other plants which are usually considered easy to bud. Mr. Harris's method is practically the same as that recommended by Rolfs. The only difference that could seem of any importance is that the bud is simply tied with raffia instead of being wrapped with waxed cloth.

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[a] The Avocado in Florida, Bul. 61, Bureau of Plant Industry, U. S. Dept. of Agriculture.

Mr. George W. Oliver, of the United States Department of Agriculture, states that the avocado is by no means a difficult plant to bud. A healthy stock is considered by him the prime essential, and this is not often secured in the greenhouses of the North.

If the method of patch-budding with old wood that has been found successful with the mango can be used with the avocado it would greatly facilitate the introduction of desirable varieties.

SOIL.

Like a great many tropical plants, the avocado is less exacting in regard to soil than it is with respect to climatic and other conditions. The drainage and the amount of protection that the soil receives from the heat of the sun are probably the most important factors. Trees can be seen growing in a great variety of soils, but always in localities with good drainage. On the other hand, they are seldom, if ever, found in perfectly open places, with the bare ground around the roots exposed to the sun. The heavy clay soil common in Porto Rico seems well adapted to their culture, provided the trees are placed on ground sufficiently sloping to secure good drainage. The avocado is at present absent from the low, flat lands of the island, and it is extremely doubtful whether it would succeed in such localities.

CLIMATE.

The avocado in its native state is a strictly tropical plant, and none of the varieties thus far recorded is able to stand any but the lightest frosts. Although requiring tropical conditions, it thrives best in a somewhat more moderate climate than the mango, and it will seldom be seen in the extremely hot localities where the mango often luxuriates. This may, however, be due to a lack of sufficient moisture, as well as to the high temperature. On the other hand, the avocado will be found growing at much higher altitudes, and here again it is not plain whether the reduced temperature or the increased moisture is the determining element.

To be successfully grown, the tree must be planted in protected situations if the locality is at all subject to high winds; for the wood is not strong enough to withstand any severe strain, while the large fruit would, of course, be beaten off by any high wind occurring when it was reaching maturity.

In Guam, according to Mr. W. E. Safford, although repeatedly introduced, the avocado has never succeeded, owing to the hurricanes, which invariably kill the trees that otherwise do well. The injury in this case is due to the excessive rainfall as well as to the high wind, a wet situation being fatal to this plant.

CULTIVATION.

The avocado is seldom regularly cultivated, so that little can be said of it in this connection except in the way of conjecture. The best fruit now produced is probably from trees that receive little or no care. This may, however, be due to the fact that the countries where such fruit is grown possess superior varieties or that the natural conditions are more favorable, and should not be taken as indicating that the fruit can not be improved by cultivation. In Porto Rico the trees in their wild state are such prolific bearers that there seems little to be desired in this direction.

The avocado would probably receive little or no benefit from having the ground about its roots stirred, as it is almost impossible to do this and prevent washing from the severe rains, and it is much better to secure protection from some low-growing plant that will not exhaust the soil. Leguminous plants would doubtless be the most satisfactory, and in Porto Rico there are several that could be so utilized. Some useful plant belonging to this group might serve as a catch crop and at the same time afford the necessary protection to the soil.

In France it has been recommended that grafted plants be grown on fruit walls, in the same manner as citrus trees.

IMPROVEMENT.

If experiments in improving avocados through breeding have been tried the results seem never to have been published. Individual growers must have done more or less selecting, and accounts of their results would doubtless be of considerable value to breeders.

The points to be kept in mind in any attempt to improve the avocado are: (1) Shipping qualities, (2) uniformity, (3) extension of season, (4) seed reduction, (5) texture, (6) flavor, (7) yield, (8) size, (9) resistance to cold.

SHIPPING QUALITIES.

To the growing of avocados in other than subtropical regions there is perhaps no obstacle so great as the difficulty of placing the fruit on the northern markets in good condition. To overcome this, more can be expected from the introduction of new varieties and improved methods of packing and shipping than from any changes brought about by cultural means. Any advance, however, that can be made in the keeping and shipping qualities will be of the greatest importance.

Under the head of varieties are discussed the thick-skinned forms grown in Guatemala, and their introduction into Porto Rico bids fair to be a distinct advance. The improvement of the existing forms in this respect by hybridization and selection is, as with all other characteristics, an untried field. The chief drawback is, of course, the length of time that must elapse before the young plants reach fruiting age. The tree can, however, be grown with little care; and with the experiments carefully outlined, so that the desired results may be kept in view, the trouble and expense would not be great, and in time some really valuable results might be expected.

UNIFORMITY.

With the avocado, as with other fruits, a regular market can only be expected when there is a regular supply of a uniform product. In Porto Rico the fruit varies in form from almost spherical to those that have a long, curved neck. The extremes probably represent distinct wild strains, but the fruit seems to come true to seed to only a limited extent, and anything like perfect uniformity can only be expected with asexually propagated plants. Rolfs[a] shows that the varieties in Florida do not come true to seed.

EXTENSION OF SEASON.

Extension of season is an important desideratum, especially in the direction of later fruiting forms, the desirability of which is considered farther on. Advance in this direction is likely to be made by the introduction of new varieties and, perhaps, by extending the cultivation of the trees to regions of more continuous moisture where the season of flowering can be to some extent controlled. The tree flourishes in many localities where it fails to bear fruit, and, as with the mango, this sterility is usually found in localities of almost continuous humidity. Under such conditions an artificial check, such as root pruning, has been found to induce flowering and the setting of fruit. This can easily be overdone, however, in which case the trees will bear one large crop and then die.

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[a] Rolfs, P. H., Bul. 61, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1904.

Some of the most prolific trees are those grown in rather small depressions of porous rock in southern Florida, where the plants are, in a manner, root-bound, while the porous nature of the rock affords good drainage. There are a number of ways in which the growth may be checked and the yield increased. The baring of the roots to the sun would appear a very satisfactory method. A custom of hacking the trees to make them bear is practiced by the Indians of Mexico. In any case where the fruiting is induced by artificial means the season will be more or less under control.

SEED REDUCTION.

In most forms of avocado the seed forms a considerable proportion of the bulk of the fruit, and its reduction is to be desired. As pointed out by Rolfs, it is important that the seed should fill the cavity, as otherwise the movement of the seed during shipment damages the pulp.

Modern discoveries in evolution and plant breeding make it evident that the character of seedlessness in a fruit, though rarely secured, may be sought in either of two ways: (1) If the plant is normally open fertilized, self-fertilization and selection for a number of generations will in many cases produce sterility, and consequently seedlessness. (2) By artificially pollinating the flowers with pollen from a variety or species so far removed that the fertilization is imperfect, the exocarp or other parts of the fruit that are entirely the product of the female parent may develop, while the seed, which is the result of the union of the male and female elements, remains small or is aborted entirely.

As the avocado is open fertilized, the first method mentioned is perhaps more simple, but will take more time, and this is, of course, a great disadvantage with fruits that are so long in coming to bearing.

The second method necessitates sufficient skill to effect hybridization, and this of the most difficult kind, but has the advantage of securing much quicker returns.

The element of time is of so much importance that, if possible, all methods should be tried simultaneously.

Rolfs[a] states that a seedless avocado has been discovered in Florida, but does not say whether the fruit is otherwise desirable or not.

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[a] Bul. 61, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1904.

TEXTURE.

The fine, creamy texture of the avocado plays an important part in winning admirers of this fruit. If free from fiber, the texture is usually not unlike that of very soft cheese. Lack of uniformity is the greatest danger, for if the flesh is uniform and free from fiber it leaves little to be desired. The manner in which the fruit is ripened probably has more to do with the uniformity and nature of the texture than does the variety. Poorly formed fruit, or fruit that has been picked too green, will often have the flesh soft and discolored in some places, usually near the skin, while the remainder is hard and unripe. Careless packing, so that the fruit is subjected to pressure at some point, will also bring about this undesirable condition. For shipping, the fruit must, of course, be picked green, and to insure uniformity in ripening it must be packed with the greatest care.

FLAVOR.

So far as observed, the most delicious and highly flavored avocados are some of the small, thick-skinned, and thin-fleshed forms of southern Mexico and Central America. The advantage, however, is slight, there being much more uniformity in the flavor of the different forms of the avocado than in most fruits. A really poor or disagreeable flavor has never been noted, except, perhaps, in cases where the fruit ripened unevenly, and then it is usually due to the part eaten being either green or overripe. Improvement in this character might slowly be brought about by selection, or perhaps by crossing with some of the small and more highly flavored forms.

YIELD.

Avocados have been subjected to careful cultivation for such a short time that little is known concerning the conditions that influence yield. As with most tropical plants, climate has probably a greater influence than soil, and judging from the fact that in nature the trees frequently drop their leaves before the fruit matures, it may be expected that a rather decided alternation of wet and dry seasons is an essential.

In Hawaii it appears that several fruits in the same cluster mature. This has never been observed in Central America or the West Indies, where large numbers of the fruits set, but all but one of each cluster drop while still young.

If commercial fertilizers are applied, it would seem that the proper time is immediately after the young fruits have set.

SIZE.

The largest avocados that have come to our immediate notice are those in Porto Rico. (Pl. II.) Travelers in Colombia, however, report much larger fruit, and both Hawaii and Florida probably produce fruit as large or larger than any in Porto Rico. Large size in the avocado is not such a prime essential as with many fruits. Even a medium-sized fruit is usually large enough for two people, and large samples might with a certain class of buyers be less desirable. Of course, this should not be taken to mean that a tree that bears large fruit is less desirable than one that bears small fruit, but only that it might not be well to go to much trouble or expense to secure varieties that excel only in size. With improved cultivation the size of the fruit will doubtless be increased to some extent without the introduction of new forms.

RESISTANCE TO COLD.

An avocado able to withstand slight frosts would place the industry in Florida and California on a much more secure footing. Forms having this quality are likely to be found in the highlands of Central America and Mexico. A form from Monterey that withstands light frosts has already been introduced into California and Florida. With this form the blossoming season is so early that in California the cold weather frequently destroys the crop. The importance of more hardy forms is apparent from the statement of certain California growers that if relieved of the danger and loss from frosts the avocado would be the most profitable fruit to grow, there being a ready market and good prices.

DISEASES.

The only diseases of the avocado thus far reported are those mentioned by Rolfs[a] as occurring in Florida. Similar diseases doubtless exist in other localities and will be reported as soon as the culture receives the same attention that has been given it in Florida.

Trees of the round thick-skinned form growing in Guatemala were found to have their leaves badly infested with galls and also were eaten by a caterpillar. Apparently the same galls were here found growing on the wild relative of the avocado—the "coyo."

D. L. Van Dine[b] figures an avocado leaf infested with mealy bug. So far as known the flesh of the fruit is never troubled with insect pests, a remarkable fact if true, for the flesh would seem to form an ideal medium for their depredations.

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[a] Bul. 61, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1904.

[b] Insecticides for Use in Hawaii, Bul. 3, Hawaii Agricultural Experiment Station, 1903.

The seeds of some of the smallest forms in the City of Mexico were found infested with the larvæ of an insect, and at Tapachula, Mexico, the cotyledons frequently showed large, black excrescences, the nature of which could not be determined. Neither of these troubles appeared to injure the fresh fruit, but if the fruit was kept for any length of time they might become sources of decay.

In Jamaica a fungous disease that affects coffee trees is said to be definitely associated with the roots of dying avocado trees. It is described in the following extract:[a]

> A coffee planter suffered serious losses from the sudden dying out of trees on certain fields. As guano had been employed as a fertilizer on these lands some years before, the planter attributed the mischief to the fertilizer.
>
> On visiting the cultivation, I found that the damage was caused by a root fungus and that there was a definite connection between the roots of dying or dead avocado pear trees and the affected coffee. Microscopic examination confirmed this view. I have examined similar samples from other parts of the island which confirm the view that the pear should not be grown on any lands intended for subsequent cultivation.

THE AVOCADO IN PORTO RICO.

With the possible exception of the pineapple, the avocado is perhaps the only fruit which Porto Rico is at present producing of sufficiently high quality to enable it to compete successfully with the fruits furnished by the more highly developed tropical regions. The quantity is also sufficient, although the season is at present short, to warrant the opening of a trade with the United States.

First among the difficulties is the fact, already noted, that the public is at present little acquainted with this rather unusual form of fruit. There is, however, already demand enough to show that it is likely to suit the American taste. Again, the fruit reaches our public in such small quantities that few have a chance to test it.

That Porto Rico does not participate in the small consignments that are now received in the United States is largely owing to the difficulty in shipping the fruit so that it will reach its destination in a marketable condition. With the varieties now in Porto Rico it seems doubtful whether this can be done except by shipment in cold storage. There are numerous other difficulties with the present conditions which would have to be taken into account before success can be assured. The trees, though numerous in the aggregate, are so scattered—there being no plantations—that it is difficult to secure anything like uniformity in the shipments. The natives allow the fruit to become nearly ripe before it is gathered, in which condition it will probably not ship well even in cold storage. The fruit is not carefully gathered, but is knocked off the trees, a method which completely destroys the keeping qualities of the varieties now growing in Porto Rico.

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[a] H. H. Cousins, June 23, 1904, Supplement to Jamaica Gazette, 194.

The shortness of the season is another obstacle in the way of making the shipping profitable. This can probably be lengthened to a considerable extent by the introduction of new varieties and the proper selection of the localities where the fruit is grown. Shipments made from Porto Rico would, however, fare much better if they could be supplemented by shipments from other countries in which the fruit ripens at a different season. Porto Rico, Mexico, Central America, Hawaii, Florida, and California can probably supply the United States with avocados throughout the entire year.

By placing the fruit in cold storage it would doubtless reach New York in a salable condition. This would be, however, a continuous expense, even if it were found that the fruit was uninjured, and a variety that will ship at ordinary temperatures would have decided advantages. That such varieties exist is demonstrated by the successful shipment of Cuban fruit. It is furthermore believed that the thick-skinned varieties of Guatemala will prove even better keepers than those of Cuba.

In establishing the industry in Porto Rico the first step is, consequently, the introduction of better shipping varieties.

THE AVOCADO IN HAWAII.

Very fine avocados are grown in the Hawaiian Islands, particularly on Oahu, in the vicinity of Honolulu.

The chief difficulty here is the danger from high winds, confining the industry to sheltered localities.

Prices in Hawaii are high in comparison with most regions where the fruit is grown, and San Francisco affords a ready market. On page 40 is a short account of an experimental shipment in cold storage, showing that by this means the fruit can be shipped not only to San Francisco, but to points as distant as New York.

THE AVOCADO IN FLORIDA.

The culture and propagation of the avocado have recently received greater attention in Florida than in any other locality. A special bulletin on the subject by Mr. P. H. Rolfs, pathologist in charge of the Subtropical Laboratory at Miami,[a] gives the status of the culture in that region, together with directions for cultivation, asexual methods of propagation, descriptions of forms, etc.

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[a] Bul. 61, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1904.

In spite of the fact that nearly all of the avocados north of the southern end of Merritts Island were killed to the ground by the freeze of 1894–95, showing the avocado to be no more hardy than the mango, planters have been by no means discouraged. Orchards of considerable size exist and the asexual propagation of the better forms is being rapidly pushed. There seem, however, to be but two, or possibly three, well-marked types in Florida, and the chances of securing desirable varieties for asexual propagation might be greatly increased by the introduction of some of the better forms from Central and South America. In Florida the shipping quality of the fruit is not of such prime importance as in Porto Rico, and consequently the choice of varieties should differ in the two localities.

THE AVOCADO IN CALIFORNIA.

The growing of avocados in California is at present restricted to the very limited frost-free areas. In many localities where the frosts are very light they would do little or no damage did they not occur at the time of blossoming, thus destroying the crop.

A slightly later flowering variety would avoid this and considerably extend the range of culture.

There is a good local market for avocados in California, prices being fully as high and the fruit as popular in San Francisco as in the eastern cities.

BEARING AGE AND LIFE OF TREE.

In favorable localities avocado trees will come into bearing about the fourth year from the seed. In more temperate regions, like southern Europe, it requires six or seven years. Budded or grafted trees should come into bearing somewhat earlier. If the tree makes a good growth, the yield should continue to increase until the tenth or twelfth year.

The next point to be considered is the probable life of the tree. Ramon de la Sagra gives this as about 80 years. This is probably not a high estimate, for very old trees are common in most tropical countries. In the opinion of Mr. Henry Davis[a] trees are still growing in the northern part of Peru which antedate the advent of the Spanish settlers. Some of these trees are fully three feet in diameter. Neither do old trees appear to become less productive.

YIELD.

The yield of an avocado tree when in full bearing is quoted as ranging from 50 to 500 fruits. In Hawaii the yield is said to be from 50 to 250 fruits, being larger in alternate years. There is an actual record of a tree in California that yielded 500 fruits in its eighteenth year. In Porto Rico, while none were actually counted, the average yield of a full-grown tree would surely seem to be above 100.

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[a] Hawaiian Forester and Agriculturist, 2: 66, 1905.

Rolfs states that the yield is usually overestimated owing to the fact that trees with few or no fruits are overlooked. An orchard of 110 trees of bearing age, near Buenavista, Fla., was found in 1903 to yield an average of only 10 fruits per tree. The most prolific tree bore 385 fruits.

HARVESTING.

TIME TO PICK.

The degree of maturity which the fruit should attain before it is picked depends, of course, on the length of time it must be kept. There is, however, no evidence that the quality is improved by fully ripening on the trees, and in countries where the fruit is gathered for local consumption it is customary to pick and store it several days before eating.

In most varieties when the fruit is fully ripe the seed does not entirely fill the central cavity, but whether it should reach this stage before picking has not been definitely determined.

This failure of the seed to fill the cavity is probably due to a slight shrinking of the flesh, the result, possibly, of evaporation after the fruit has ceased to receive nourishment from the tree. The beginning of this process would seem to indicate the maturity of the fruit. In the absence of definite information it seems probable that the best results will be obtained with fruit picked when fully grown, but before it has begun to ripen. Dybowski[a] recommends that the red varieties be picked as soon as they begin to color and the green ones when the color begins to become lighter. Many of the green varieties, however, do not change color appreciably on ripening.

METHOD OF GATHERING.

The picking of the fruit, although a matter of prime importance, is one that has been given no consideration. In Florida, where the avocado has received the most careful attention, the trees seldom reach a height at which it is impracticable to use stepladders, but in the Tropics, if the trees are at all luxuriant, they place most of the fruit entirely beyond this method of access. In these countries the fruit is usually knocked from the trees with long poles or the tree is climbed and the fruit shaken to the ground, which, of course, ruins its keeping qualities and causes it to ripen unevenly.

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[a] Traité Pratique des Cultures Tropicales, 451, 1902.

Until some satisfactory method is devised for gathering the fruit without bruising and with the stems attached, the shipping qualities of the fruit from tall trees are likely to prove unsatisfactory.

The wood of the avocado tree is so brittle as to make the use of ladders impracticable, and this, together with the fact that the fruit is borne far out on the ends of the branches, also makes it impossible to gather the fruit by climbing the trees.

It would seem that the most feasible method of gathering avocados would be the using of some form of mechanical fruit picker, mounted on a slender pole. Numerous styles of this implement are to be found on the market, but perhaps none will answer the purpose without alteration.

The fruit picker that seems best adapted is one that has a cloth tube along the side of the pole into the upper end of which the fruit drops and down which it slides into a basket attached to the waist of the operator. Most of the pickers of this type, however, have merely claws to pull the fruit from the trees, and it may be necessary to combine this cloth tube with one of the long pruning instruments that are on the market, that the fruit may be cut and not pulled from the trees.

Fruit pickers so constructed as to pick the fruit by cutting the stem are on the market, but these for the most part catch the fruit in a little basket or bag at the end of the pole and necessitate the lowering of the picker from the tree after two or three fruits are picked, whereas the arrangement first described need not be lowered.

C. Riviere[a] calls attention to the fact that the avocados common on the south side of the Mediterranean and in Madeira and the Canary Islands are very short stemmed or sessile, whereas the American forms, so far as known, all have comparatively long stems, though varying greatly in this regard. The writer also calls attention to the fact that the long-stemmed forms are more desirable, it being difficult to pick those that are nearly sessile without pulling the fruit from the stem and thus injuring the keeping qualities of the fruit.

PACKING AND SHIPPING.

The lack of good shipping qualities in the avocado is probably the most serious obstacle to the rapid development of the industry in the West Indies and is certainly the chief reason why Porto Rico does not participate in the small shipments that are now made to New York. That it is possible without cold storage to ship avocados from Cuba, while all experiments with the Porto Rican fruit have proved failures, makes it evident that a study of the causes of this difference is of prime importance. It is believed that the better keeping and shipping qualities of the Cuban avocados are due to the characteristics of the fruit rather than to differences in gathering or packing. Indeed, this might be inferred from the appearance of the fruit, that of Cuba having a thicker and harder skin than the Porto Rican forms. The introduction of the thick-skinned varieties from Guatemala should give Porto Rico a decided advantage, for it is believed that the Guatemalan forms will prove even better shippers than those of Cuba.

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[a] Journal d'Agriculture Tropicale, 222, July, 1904.

Though avocados are successfully shipped from Cuba, Florida, Mexico, and other places to northern cities, and many different styles of packing are employed, little can be learned from these experiments as to the best method, since no account is taken of the variety of the fruit, which is undoubtedly a more important factor than the method of packing. That avocados from Cuba, wrapped in newspaper and packed in large crates, have come through in better shape than those from Porto Rico, wrapped in tissue paper and packed in crates only one layer deep, does not necessarily indicate that the former method of packing was superior, but it may mean that the Cuban fruit was such a good shipper that it kept in spite of the inferior method of packing.

From a comparison of the different methods of packing that are practiced, taking into consideration as far as possible the nature of the fruit, it seems, however, that the avocado, like most tropical fruits, keeps best when packed in such a manner as to be protected from jars or any undue pressure and in such a way that the fruit is well ventilated. Another important consideration with the thin-skinned forms is that they be packed so that the individual fruits do not come in contact with each other, for, even with the greatest care, bruised fruits will frequently be included. These will rapidly decay, and if not isolated will induce decay in those with which they come in contact. This danger is much less with the thick-skinned forms.

These conditions are very satisfactorily met by packing the fruits in fine excelsior or some similar substance in rather open cases that are not so large as to prevent those on the inside from being ventilated. If the fruits be wrapped, it should be with some porous paper, but where they are separated from each other this precaution would seem unnecessary or even detrimental.

The amount of ventilation the fruit should receive undoubtedly depends on the variety and still more directly on the temperature, fruit in cold storage requiring little or no ventilation.

The best results in the shipments to New York of avocados from Cuba have been obtained with the fruit wrapped in newspaper and packed in open crates but one layer deep. Tissue paper was tried, but it was said not to offer sufficient support and did not prove as satisfactory as the newspaper.

Florida growers report that they experience no difficulty in packing their fruit so that it reaches the northern market in good condition. The more careful shippers, however, pack the wrapped fruit in excelsior.

The few experiments that have been tried in shipping Porto Rican avocados, other than in cold storage, have, so far as can be learned, resulted in every case in almost complete failure. Little could be learned as to the methods of packing that were employed. In one case, however, the fruit after being wrapped in tissue paper was again wrapped in oiled paper. In this instance the fruit was practically all rotten when it reached New York. It seems more than probable that the fruit would have shipped better without the oiled paper, as this packing would very effectually prevent all ventilation, a necessity at all ordinary temperatures. A very important consideration in the keeping qualities of fruit, brought to the writer's attention by Mr. William A. Taylor, of the Department of Agriculture, is the climatic conditions that prevail at the time the fruit is packed. Fruit packed in a dry climate has been found to keep much better than the same fruit packed when the atmosphere is moist. This is doubtless true of the avocado and may explain the successful shipment from southern Mexico to New York of varieties that appear to differ but slightly from those of Porto Rico.

COLD STORAGE.

In cooperation with Mr. William A. Taylor, pomologist in charge of field investigations, and Mr. Jared G. Smith, director of the Hawaii Agricultural Experiment Station, an experiment was tried of shipping avocados in cold storage from Hawaii to New York City.

Five crates of avocados were packed and shipped in cold storage from Honolulu about September 25, reaching San Francisco on October 4. From San Francisco they were expressed to Lodi, Cal., and during this transfer they were exposed to air temperatures for from six to eight hours. At Lodi they were again placed in iced cars and sent directly to New York City, where they arrived on October 20. The fruit was consigned to Messrs. Lane and Son, who forwarded samples to Washington. It will thus be seen that the fruit was thirty days in transit. Although the majority of the samples were found to have suffered from the long trip, some of the lots were in good condition, thus demonstrating that, with a knowledge of how to handle the fruit, even the more delicate forms can be successfully shipped in cold storage, provided the fruit is not more than three or four weeks in transit.

That this experimental shipment was hardly a fair test is shown by the statements of Mr. J. E. Higgins, who superintended the shipping of the fruit at Honolulu. In a letter to Mr. Taylor he says:

> Most of the pears were by no means representative. The pear season was about over when we learned from you that there was an opportunity to make the experimental shipment. The fruits were inferior in size, only those marked F 13 being first-class specimens in this respect. It being the end of the season, the fruits, though hard, were of course quite fully matured. The fruit was picked several days before the sailing of the steamer and was held in cold storage until it could be received at the ship.

Shipments of avocados, made at air temperatures, are frequently placed in cold storage as soon as they reach New York. This process is resorted to in the effort to hold the fruit for the fall trade, and, even though the loss be heavy, the increased price still makes it a profitable procedure. There is a very uncertain element involved in this, for with fruit that appears uniform when placed in cold storage some comes out in perfectly sound condition, while the remainder will be completely decayed. This lack of uniformity in the keeping qualities is probably due to the different degrees of maturity at which the fruit is picked and to the conditions to which it has been subjected in transit, it being very difficult to detect such differences from the outward appearance of the fruit.

As to the best temperature, amount of ventilation, method of packing, etc., little is known. Dybowski[a] states that shipments have been made in cold storage from the Antilles to France, and that a temperature of 2° C. (35.5° F.) was found the most satisfactory. He recommends that the fruit be wrapped in paper and packed in excelsior. Shipments made in this way are said to reach France in good condition.

MARKETING.

The market for avocados is at present a limited one, the fruit being still somewhat of a novelty. It is, however, steadily increasing and from present indications will keep pace with the supply. The fruit is already fashionable, and if uniformity in the supply both as regards quantity and quality could be secured and the prices somewhat reduced, as could well be the case were large quantities of the fruit handled, its popularity would rapidly increase.

Lack of classification is perhaps the greatest hindrance to the development of a regular market. Fruits more widely different than "Ben Davis" and "Northern Spy" apples are all classed as avocados without further distinction. This lack of classification is accompanied with a corresponding lack of uniformity and must seriously hinder the growth of the trade. Not only may two shipments of avocados be totally unlike, but the individual shipments often contain distinct forms of a widely different character. Plates VI and VII show two samples from the same box. These fruits, so distinct in form, were no less different in flavor, and both were very inferior. The size and external appearance, as well as the price (35 cents apiece), would lead one to expect that he was purchasing fair specimens of the fruit, but if an opinion was formed from such specimens as these it could hardly be other than that the fruit was insipid and in no way worth the price asked.

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[a] Traité Pratique des Cultures Tropicales, 450, 1902.

In sections where the fruit is unknown a demand is more rapidly created by inducing hotels, clubs, etc., to include this article in their menus than by merely exhibiting the fruit in the markets, for while many might be led to purchase samples of this strange fruit if seen in the market, they would frequently be ignorant of its use as a salad, in which case they would probably pronounce it insipid and might be deterred from further trials. On the contrary, anyone tasting for the first time the prepared salad would usually be pleased and would be likely to investigate the source of the new dish.

In Washington this fruit has sufficient admirers to warrant the frequent insertion of a notice in the papers, by dealers, to the effect that a shipment of avocados is on hand. The shipments, though small, are fairly regular, and there are one or two places where the fruit can usually be found during the season.

In the present state of the market there is nothing like a fixed price for avocados. In New York and Washington the usual retail price may be said to be about 25 cents for good fruit; 60 cents is, however, frequently asked for fine fruit, and fair specimens can sometimes be purchased as low as 10 cents. This low figure is, however, never reached except in cases where large shipments have failed to be disposed of and the fruit is in serious danger of spoiling.

With reference to the San Francisco market, Alexander Craw states:[a]

> Sound "avocado pears" always meet with a ready market in San Francisco, and at good prices, at times ranging from $2 to $5 per dozen, retail, for good fruit. Occasionally there is a heavy drop, owing to the arrival of overripe or badly packed fruit. In selecting avocado pears for distant markets see that they are as nearly full grown as possible, but hard. On no account should the fruit be plucked from the tree, but clipped with pruning shears, leaving but a very short portion of the stem—not over half an inch in length. On no account must any leaves be packed with the fruit, or the horticultural quarantine officers of the Pacific ports will demand the unpacking of such consignments, as occasionally a few scales are found on the foliage, but not on the fruit.

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[a] Hawaiian Forester and Agriculturist, 2: 67, 1902.

The following, taken from the Crop Reporter of the Department of Agriculture, January, 1903, gives some indication of the prices in England:

> With regard to the newer fruits which are attracting attention in the English markets, there are several which call for special reference. Among such are the avocado pears. These pears are high priced, selling from 1s. to 1s. 3d. (24 to 30 cents) each, retail.

MARKET SEASON.

The regular season for avocados is in the summer and the early autumn, the bulk of the fruit being received during the months of August and September. This is the most unfavorable time for a tropical fruit of this kind to be placed on the market, for not only does it come in competition with the fall fruits, but at this time large numbers of the admirers of this fruit are away from the cities at summer resorts, and in order to reach the best class of customers the fruit must be reshipped. This feature of the trade is so important that commission merchants can afford to hold the fruit in cold storage for this class of customers until they return to the cities, and this in spite of the fact that the fruit reaches them in such an advanced stage that but a very small percentage is salable when taken from cold storage. In cities like New York, the Cuban and Spanish populations are always ready to purchase avocados, but this class will buy only at a comparatively low price, which under present conditions serves merely to protect the merchants from total loss. Florida growers say that for fruit that they can hold until the latter part of September or into October they can ask their own price. It will thus be seen that it is of the greatest importance to secure late-maturing sorts.

With the improvement of transportation facilities and good shipping varieties the northern markets can probably be supplied with avocados every month in the year. In fact, February is probably the only month during which no avocados are received in New York. Outside of the regular season, however, the shipments consist of a few fruits brought in the ships' ice boxes. Of these, the earliest are said to come from Colombia and the latest from Santo Domingo. A possible schedule would be as follows: Florida, Porto Rico, and Cuba, June to November; Hawaii, September to December; Mexico, December to March; Central America, March to June. To dealers familiar only with the West Indian type of fruit the shipping of avocados from such distant points as Central America will seem entirely impracticable. The keeping qualities of the thick-skinned forms of Central America make this, however, not at all impossible provided the picking, packing, and shipping be handled in an intelligent manner. Indeed, small shipments have already been made from the City of Mexico to New York via Los Angeles, where the fruit was repacked, and this with a comparatively thin-skinned variety.

Viewed from the standpoint of the producer, however, the question is not how can the market be supplied throughout the entire year, but how can avocados be produced in our own possessions at a time to command the best prices. Too great confidence should not be placed in the introduction of early or late fruiting varieties from other countries, for the season of fruiting is to a great extent the result of climatic conditions, and an early fruiting form in Guatemala if transferred to Porto Rico might soon become no earlier than the native kinds. In a general way the fruiting season is found to be about the beginning of the rains. In Porto Rico different parts of the island exhibit considerable disparity as to the time that the rains begin, and by carefully selecting localities with this in mind the season might be materially extended. Selection for this character would probably be well repaid, as it has been with so many other fruits, but unless asexual methods of propagation are practiced, too much confidence should not be placed in the ability to hold this or any other character obtained through close selection. In localities with comparatively uniform climatic conditions the growing of avocados under irrigation might have important advantages, for if any method of artificially inducing the plants to bear should be successful it would be possible to control the season by checking growth at the proper time.

METHODS OF EATING.

By far the most common method of eating the avocado is in the form of a salad. As such it is eaten raw with a great variety of dressings and condiments. Few salads are so easily prepared as the avocado. Usually the fruit is simply cut in half by passing a knife through the skin and flesh until it comes in contact with the seed. It will then separate into two cups, forming convenient receptacles for the seasoning, which is added a little at a time to suit the taste, and the flesh is scooped from the inside of the cup with a spoon. One half of the fruit is usually sufficient for a person at a meal. The most common dressing is salt, pepper, and vinegar. Oil is often added, but unless the oil and vinegar are beaten into a mayonnaise this would seem superfluous, as the fruit is itself very oily. Lime or lemon juice is often substituted for vinegar.

While the novice usually considers some form of acid necessary to add piquancy, those better acquainted with the fruit frequently eat it with salt alone, and many think that even salt tends to mask the delicious nutty flavor, and prefer it in its natural state without any seasoning whatever. There are a few people, probably of New England origin, who eat the fruit with sugar and vinegar, and some even profess a fondness for it with a dressing of sugar and cream.

If it be desired to more thoroughly incorporate the dressing the flesh can be removed from the skin and, after mixing the whole, can be returned to the skins for convenience in serving. This is more neatly accomplished with the thicker skinned forms.

In Guatemala, Porto Rico, parts of Mexico, and doubtless elsewhere, the avocado is sliced raw and added to soups. Even a small piece of the soft pulp crushed in a plate of soup imparts a delicate flavor, and during the season of avocados the baskets of people returning from market are seldom without specimens of this fruit. In the market at Cordova the little piles laid out for individual purchasers consisted of three or four little fruits no larger than walnuts, with flesh not more than one-fourth of an inch thick. As better fruit was not to be had, even these met with ready sale, so indispensable is this article of diet considered.

In French countries the avocado is customarily served as an "hors d'œuvre." E. Roul states [a] that an exquisite dessert is made by covering the fruit with a dressing of cherry brandy, sugar, and cream beaten almost to an emulsion.

In St. Thomas the fruit is eaten with Port or Madeira wine and lemon or orange juice.

In Brazil the fruit is made into a sort of custard pudding.

The following methods of preparing the fruit, as well as that for extracting the oil, were kindly furnished by Mrs. William Owen, of Sepacuite, Guatemala:

No. 1.—Divide in half and serve in the shell, as many prefer them without the addition of salt.

No. 2.—Cut the meat into cubes, mix with sufficient mayonnaise to coat it well, put in a platter, pile high in the center, and sprinkle over hard-boiled egg chopped fine.

No. 3.—Divide in half and carefully remove the meat. Add the yolk of a hard-boiled egg and one tablespoonful of French dressing for each fruit. Press through a sieve and pile in the half shells. Garnish the tops with the white of the eggs chopped fine, a sprig of parsley, and one small red pepper.

Sandwiches.—Use thin slices of bread buttered thinly; spread on a paste prepared of mashed avocado mixed with a dressing of oil, salt, tarragon vinegar, and a little nutmeg.

Avocado oil.—Divide the fruit in half and remove the seed. Place the two halves together again and lay them in a large basket. Cover with a cloth and keep in a cool, dark place until the meat turns black; then put them into a coarse cotton bag. Sew up well and put into a press. The oil is very clear, and all the Ladinos say it will never become rancid. They never use it in cooking, though it has a pleasant flavor, but say it is fine for the hair.

The following method of preparing a salad with avocados is given by Janet M. Hill: [b]

Cut three ripe aguacates in halves, take out the stone or seed, and scoop the pulp from the skin. Add three tomatoes, first removing the skin and core, and half a green pepper pod cut in fine shreds. Crush and pound the whole to a smooth mixture, then drain off the liquid. To the pulp add a teaspoonful or more of onion juice, a generous teaspoonful of salt, and about a tablespoonful of lemon juice or vinegar. Mix thoroughly and serve at once. This salad may be served at breakfast, luncheon, or dinner.

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[a] Sagot, Manuel Pratique des Cultures Tropicales, 197, 1893.

[b] The Cooking School Magazine, 9: 153, Oct., 1904.

In a report of Mr. John R. Jackson[a] it is stated that "it is either cooked or served as a vegetable with white sauce," as well as eaten as a salad. This is the first account noted of cooking the avocado.

FOOD VALUE.

The results of the chemical analyses given below show the comparative value of the avocado for food purposes. For the following table and the statements concerning it the writer is indebted to Dr. C. F. Langworthy, of the Office of Experiment Stations of the Department of Agriculture.

Analyses of the avocado have been recently made at the Maine and the Florida Agricultural Experiment Stations.[b] The following table shows the results of these analyses and includes, for purposes of comparison, similar data regarding a number of common food products:

Composition of the edible portion of the avocado and other foods.

	Water.	Protein.	Fat.	Carbohydrates.		Ash.	Fuel value per pound.
				Nitrogen-free extract.	Crude fiber.		
	Percent.	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Calories.*
Avocado (analyzed at the Maine station)	81.1	1.0	10.2	6.8		0.9	512
Avocado (analyzed at the Florida station)	72.8	2.2	17.3	4.4	1.9	1.4	854
Pickled ripe olives	65.1	[a]5.7	25.5	3.7		--------	1,201
Pickled green olives	78.4	[a]6.9	12.9	1.8		--------	680
Apples	84.6	.4	.5	13.0	1.2	.3	290
Bananas	75.3	1.3	.6	21.0	1.0	.8	460
Pears	84.4	.6	.5	11.4	2.7	.4	295
Cocoanuts	14.1	5.7	50.6	27.9		1.7	2,760
Chestnuts, fresh	45.0	6.2	5.4	40.3	1.8	1.3	1,125
Potatoes	78.3	2.2	.1	18.0	.4	1.0	385
Wheat flour	12.0	11.4	1.0	74.8	.3	.5	1,650

[a] Including ash.

In the avocados analyzed at the Maine station the edible portion or pulp constituted on an average 71 per cent of the total weight of the fruit, the seed 20 per cent, and the skin 9 per cent. Prinsen-Geerligs,[c] in an extended study of tropical fruits, reports similar values for the avocado—i. e., flesh 67 per cent, seed 15 per cent, and skin 8 per cent. As the avocado contains about 75 to 80 per cent water and consequently 20 to 25 per cent total nutritive material, it is apparent that it is more directly comparable with succulent fruits and vegetables than with such foods as bread. As regards the proportion of the water, protein, crude fiber, and ash, the avocado is similar to common fruits like the apple, pear, and banana. In the case of nitrogen-free extract (sugar, starches, etc.) the proportion reported in the avocado was smaller than in the other fruits mentioned. The high percentage of fat in the flesh of the avocado is noteworthy, a large proportion of this constituent in succulent edible fruit being very unusual. In this respect the avocado suggests the olive, which is, of course, very rich in this constituent, the flesh containing, according to recent analyses made at the California experiment station, from 13 to 88 per cent. Generally speaking, a higher percentage of fat is found in nuts and oil-bearing seeds than in succulent fruits, the high fat content being accompanied by a low water content, as in the case of cocoanuts, cited in the table on page 46.

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[a] Agricultural News, November 7, 1903.

[b] Maine Expt. Sta. Bul. 75; U. S. Dept. Agr., Farmers' Bul. 169; Florida Expt. Sta. Rpt., 1902.

[c] Chem. Ztg., 21: 719, 1897.

Avocado fat is solid or semiliquid at ordinary temperatures and has been separated, being known as alligator pear oil, Persea fat, and avocado oil. According to Andés,[a] it has at present no commercial importance. Wright and Mitchell [b] state that avocado oil is very similar to laurel butter or bayberry fat, from *Laurus nobilis*, which consists largely of the glycerid of lauric acid, together with a little myristin and other homologues and some olein. Olive oil is quite different in chemical character, consisting of about 25 per cent glycerids of solid saturated fatty acids (palmitic, etc.) and 75 per cent liquid gycerids, mostly olein. Olive oil is known to be a valuable food product and quite thoroughly digested. It is presumable that the avocado fat is also quite thoroughly assimilated, although little can be said definitely concerning its nutritive value, as apparently few, if any, investigations have been reported which bear upon this question.

Prinsen-Geerligs [c] studied the carbohydrate constituents of the avocado and reports 1.72 per cent total sugar, which is made up of 0.4 per cent glucose, 0.46 per cent fructose, and 0.86 per cent saccharose. These figures, taken in connection with the data reported by the Florida experiment station for the total nitrogen-free extract (sugar and starch), would indicate that the starch content is not far from 3 per cent.

Considering all the available data, it seems fair to conclude that the avocado has a fairly high food value as compared with other succulent fruits, especially when its fat content and consequently rather high energy value is considered, closely resembling pickled olives in this respect.

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[a] Vegetable Fats and Oils, 215. London, 1897.

[b] Oils, Fats, Waxes, and Their Manufactured Products, 353. London, 1903.

[c] Loc. cit.

COST OF PRODUCTION.

In calculating the cost of production, the following are the chief factors to be considered: Cost of land, cost of preparing the land, seed and planting, cost of culture, age at which trees bear, life of trees, yield, cost of gathering and marketing the fruit, price and extent of the market.

The cost of land in tropical countries is governed very largely by its position with reference to transportation facilities. In Porto Rico, for example, land located along the main roads and valued at $100 an acre could apparently be duplicated in localities 5 or 10 miles distant for $2 or $3 an acre. Thus, the bulk of a crop and its adaptability to transportation over country roads are very important factors. With avocados at anything like the present prices they would constitute a very concentrated product, probably exceeding coffee in pound for pound value. On the other hand, the fruit must be delayed as little as possible after picking, which, of course, militates against the selection of land too remote from a shipping point.

The cost of preparing the land varies in different localities, but in most countries this item can be estimated with considerable accuracy, as land is usually cleared by measure.

With labor at a reasonable price the seed and planting ought to cost not more than 10 cents per tree, and this with trees 20 feet each way, making 109 to the acre, would aggregate $10.90 an acre. The cost of culture would also vary greatly in different localities, but this again can in each locality be reckoned with considerable accuracy, together with the rebate to be allowed for catch crops.

Where orchards are started from choice varieties by asexual methods of propagation, an additional allowance will have to be made for budding or grafting.

Trees may be expected to come into bearing about the fourth or fifth year and may yield crops for fifty or seventy-five years.

The average yield per tree may be reckoned at 100 fruits, and should come nearer 500.

With a crop of great value like the avocado the cost of gathering and marketing is relatively small, although the fruit must be handled with considerable care, especially the thinner skinned forms.

In the present state of the market the small shipments of avocados that are received usually retail at from 25 to 50 cents apiece.

SUMMARY.

The avocado is a tropical fruit little known in the United States but rapidly growing in popularity. Its appreciation by the northern public is doubtless retarded by a misunderstanding of its true character as a food, since it is in reality a salad, being very generally eaten with condiments. This unusual rôle, however, removes it from direct competition with other fruits and tends to make its popularity permanent.

This fruit is undoubtedly of American origin, but appears to have been introduced into the West Indies after their discovery. It was an important article of food among the Indians of the continent from Mexico to Peru. It is not yet certain whether the cultivated trees belong to one or more species, botanical writers having given little attention to the many cultivated sorts. There are many wild species of Persea in this region.

Though few varieties have been described, the diversity of form is very great. In general this diversity seems to follow geographical lines, the forms of any particular region being more or less closely related. A very distinct type, with thick, hard skin, was found in Guatemala, which promises to surpass in shipping qualities the better known forms.

The avocados now found in the markets come largely from Cuba, and the chief commercial difficulty is occasioned by the poor shipping qualities of the fruit and the failure to distinguish the different varieties, the whole industry having suffered from the shortcomings of the poorer forms. Efforts to ship the delicate-skinned Porto Rican fruits have thus far failed. For this island it is recommended that the hard-skinned sorts of Guatemala be introduced. These, it is believed, will stand shipping even better than those from Cuba. Experiments have demonstrated that avocados can be successfully shipped in cold storage.

At present the season for avocados in the markets of the United States is the late summer and early autumn. By importing from different countries, however, the season could be extended throughout the entire year.

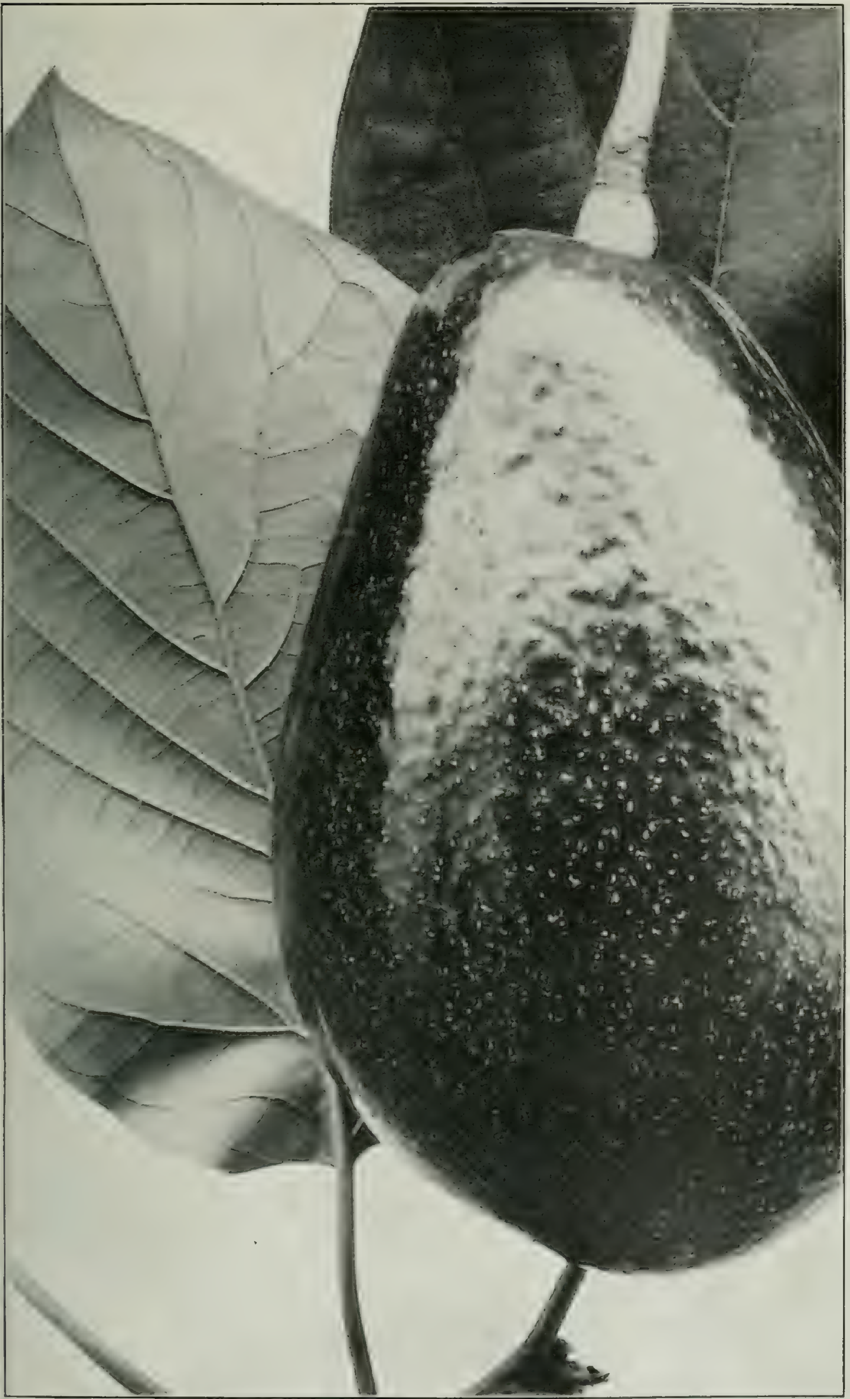
The plant requires a strictly tropical climate, with the possible exception of some of the hardy varieties of the Mexican table-lands, and to be prolific there should be a distinct dry season.

Young plants are readily propagated from seed, and budding and grafting can be accomplished, the former method being in common use in Florida.

As far as can be judged from the limited and irregular supply, the market is good, especially in the latter part of the season. Prices range from 10 to 60 cents apiece. Uniformity as regards both quantity and quality is the prime requisite for sustaining the market.

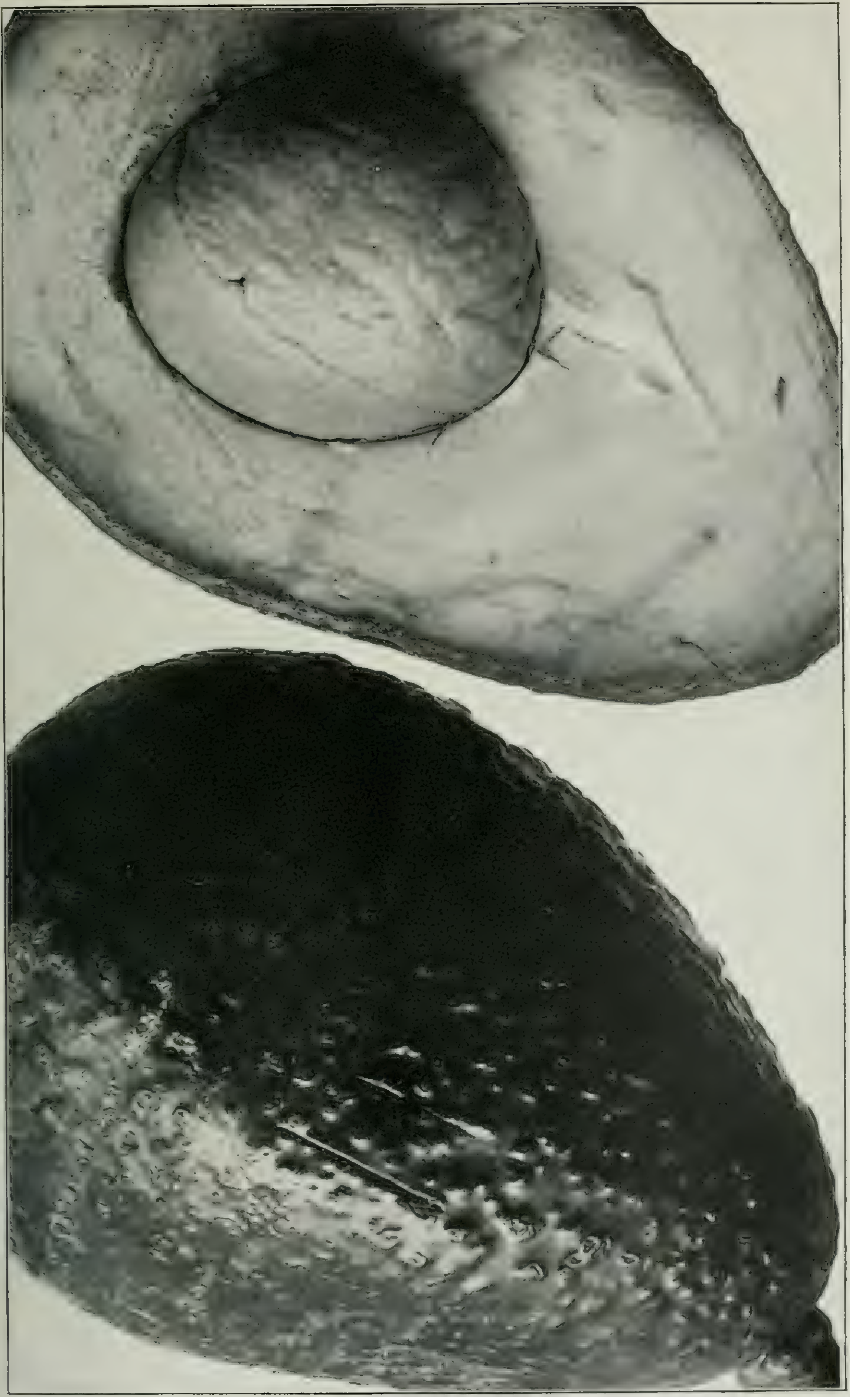
If anything like the present prices can be maintained the growing of avocados of good shipping varieties ought to become a very remunerative industry.

PLATES.



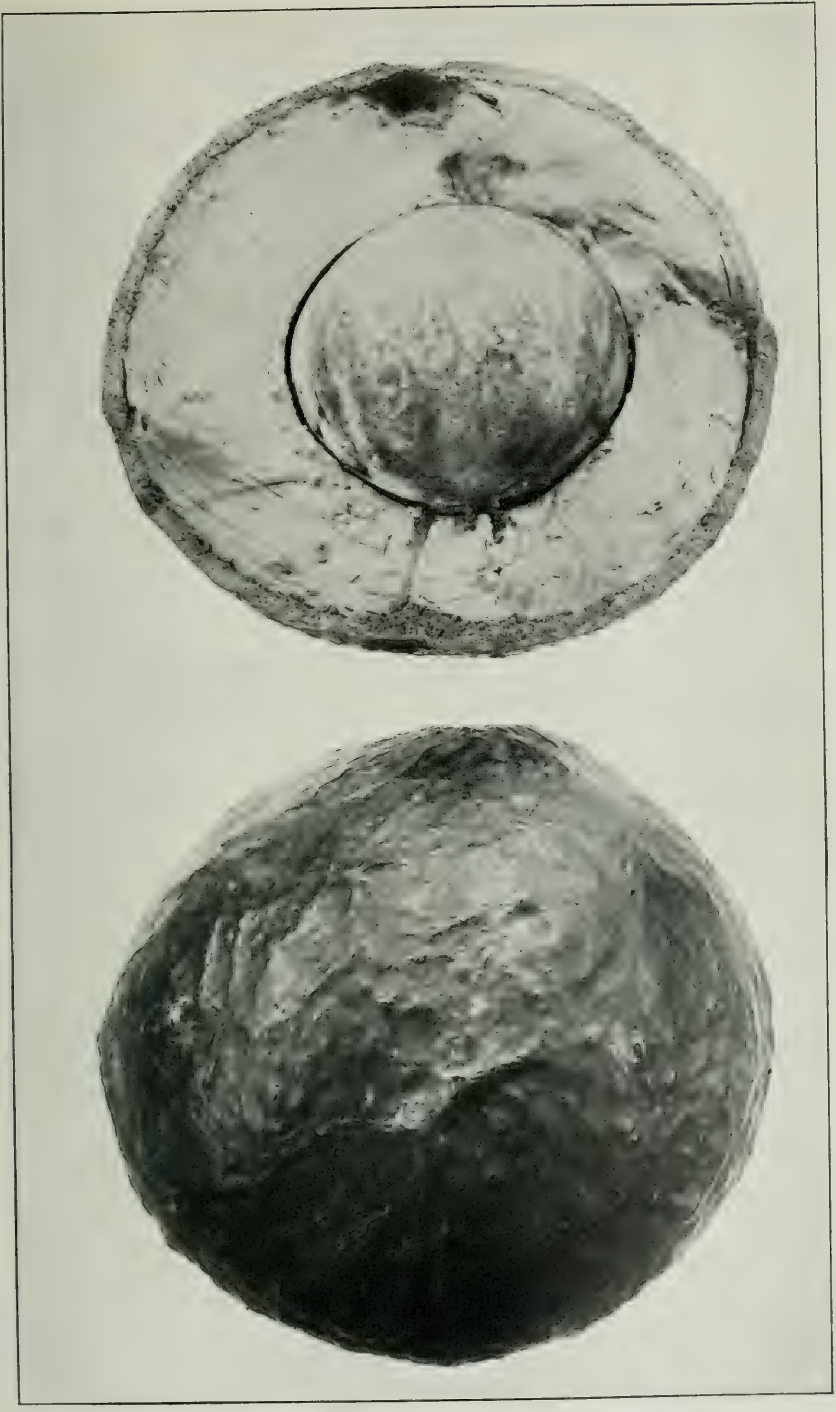
LEAF AND FRUIT OF AVOCADO, TAPACHULA, MEXICO.

(Natural size.)



AVOCADO FRUIT, "THICK-SKINNED OVAL," GUATEMALA CITY, GUATEMALA.

(Natural size.)

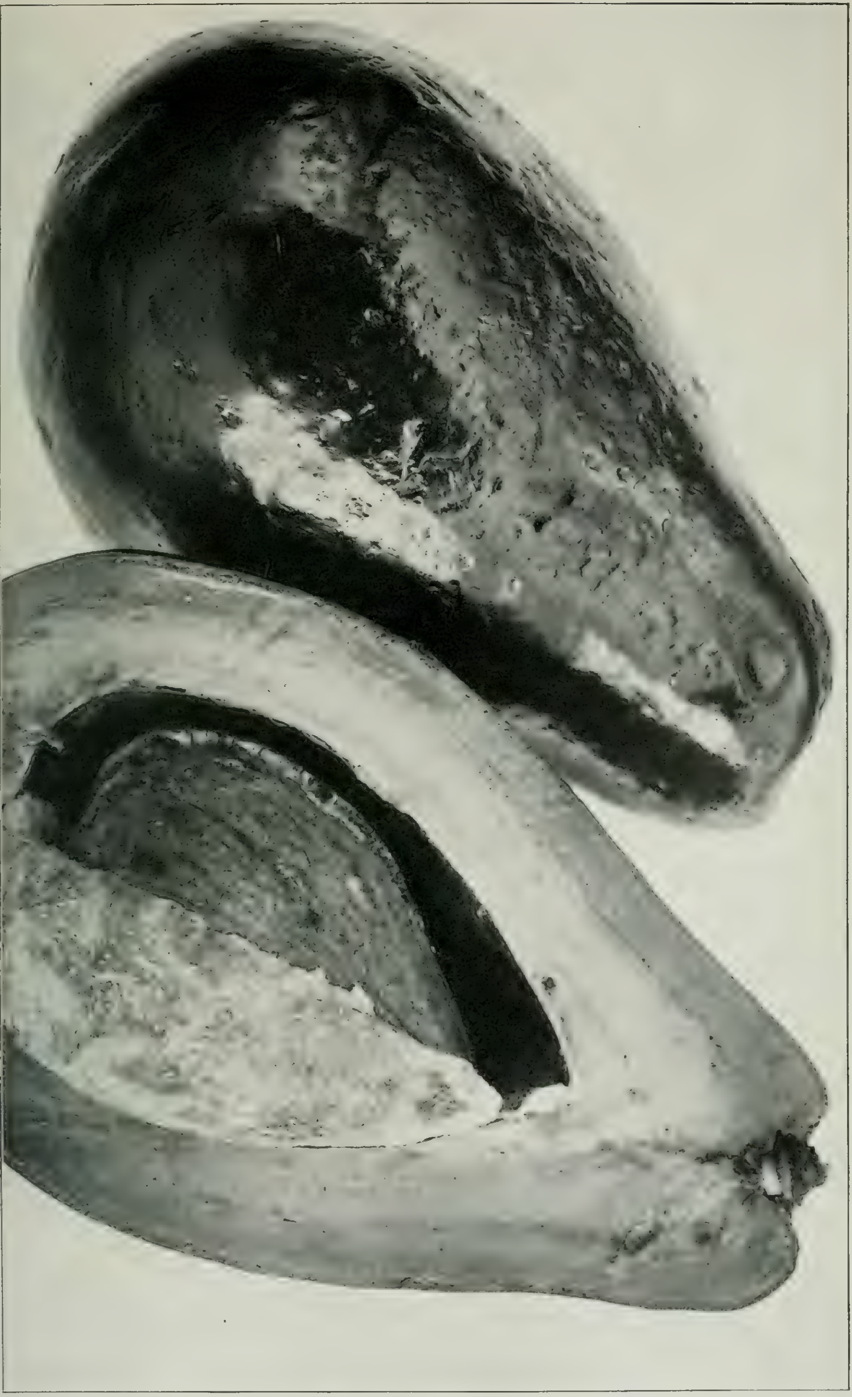


AVOCADO FRUIT, "THICK-SKINNED ROUND," GUATEMALA CITY, GUATEMALA.

(Natural size.)

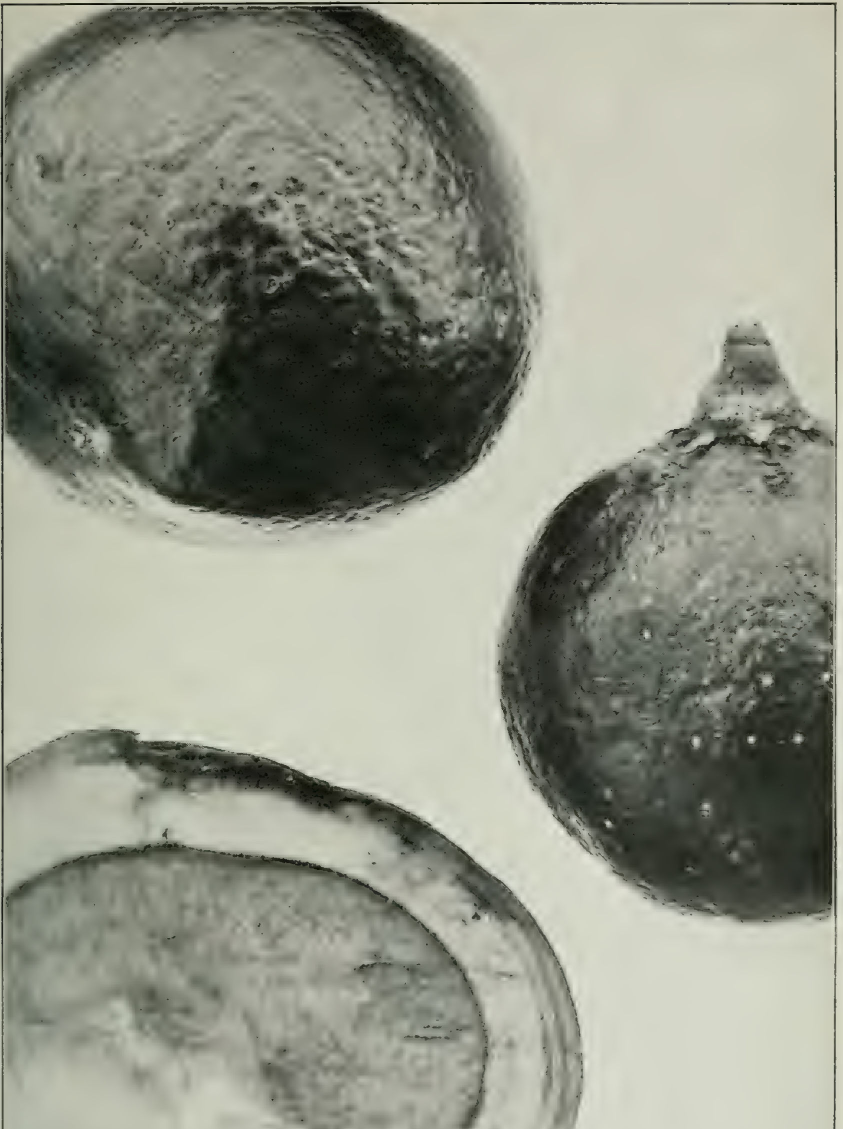
AVOCADO FRUIT, CUBA.

(Natural size.)



AVOCADO FRUIT, CUBA.

(Natural size.)



HARDY AVOCADO, OR "YAS," SAN JOSÉ, COSTA RICA.

(Natural size.)

U. S. DEPARTMENT OF AGRICULTURE.
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 78.
B. T. GALLOWAY, *Chief of Bureau.*

IMPROVING THE QUALITY OF WHEAT.

BY

T. L. LYON,
AGRICULTURIST AND ASSOCIATE DIRECTOR OF THE AGRICULTURAL
EXPERIMENT STATION OF NEBRASKA, AND
COLLABORATOR OF THE BUREAU OF PLANT INDUSTRY.

VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS,
IN COOPERATION WITH THE
AGRICULTURAL EXPERIMENT STATION OF NEBRASKA.

ISSUED OCTOBER 24, 1905.

239389
13 / 30

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

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[a] Detailed to Seed and Plant Introduction and Distribution.
[b] Detailed to Bureau of Chemistry.
[c] Detailed from Bureau of Chemistry.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., April 15, 1905.

Sir: I have the honor to transmit herewith the manuscript of a technical paper entitled "Improving the Quality of Wheat," prepared by Dr. T. L. Lyon, Agriculturist of the Agricultural Experiment Station of Nebraska, who, as a collaborator of this Bureau, is in charge of the cooperative breeding experiments conducted by the Nebraska Agricultural Experiment Station and the Department of Agriculture, and I recommend its publication as Bulletin No. 78 of the series of this Bureau.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The following technical paper on "Improving the Quality of Wheat," by Dr. T. L. Lyon, of the Agricultural Experiment Station of Nebraska, embodies the results of extended investigations on the application of chemical methods to the selection and improvement of wheat. The investigations were carried on mainly at the Nebraska Agricultural Experiment Station in connection with the cooperative work of that institution and the Plant-Breeding Laboratory of this Office.

In the breeding of wheat more extended data are greatly desired so that more intelligent methods of selection may be devised. The investigations of Doctor Lyon, it is believed, have established methods which will be of great value to wheat breeders and materially facilitate the work in their field.

This paper was originally presented as a thesis to the faculty of Cornell University for the degree of doctor of philosophy. The author wishes to express his appreciation of the guidance of Prof. I. P. Roberts, Prof. G. C. Caldwell, and Prof. Thos. F. Hunt, who constituted the committee having his work in charge, also of the assistance of Prof. L. H. Bailey and Mr. G. N. Lauman, with whom he frequently sought counsel. For the analytical work, extending through a period of seven years and involving several thousand chemical determinations, he is indebted to Prof. S. Avery, Mr. R. S. Hiltner, Prof. R. W. Thatcher, Mr. Y. Nikaido, Miss Rachael Corr, Mr. H. B. Slade, and Mr. G. H. Walker. Mr. Alvin Keyser has kept the records of wheat-breeding plats and Mr. E. G. Montgomery has assisted in keeping other records.

A. F. Woods,
Pathologist and Physiologist.

Office of Vegetable Pathological
and Physiological Investigations,
Washington, D. C., March 31, 1905.

INTRODUCTORY STATEMENT.

While the art of plant breeding has been practiced for nearly a century, the last decade has witnessed a marvelous awakening of interest in the subject, both from a scientific and practical standpoint. The keen competition in crop production and the resulting cheaper prices, the great and varying demands of modern trade conditions, etc., render it necessary that the modern plant breeder have the most thorough knowledge possible of the plant which he is striving to improve. Not only must we secure varieties and races differing in external characters and yielding more heavily under a certain set of conditions, but we must also examine the chemical constituents of the product and strive to change and improve them in order that they may better fit our purpose.

The great achievements of plant breeding in the past have been mainly in physical characters, requiring only superficial knowledge and gross examination for recognition. Many of the improvements now demanded, however, require the most careful chemical examination of the product and the devising of careful means and methods of selection based on the knowledge thus obtained.

The first and still the most noteworthy achievement of this nature is the increase of the sugar content in the sugar beet. When the work on this subject was first started by Louis Vilmorin, the mother beets, which were supposed to contain the most sugar, were separated by their greater density, this being determined by throwing the beets into a solution of brine of such density that the greater number of them would float. The few heavier ones which were found to sink were retained as mothers and planted to raise seed. Later the methods were improved, and finally the percentage of sugar content in the different individual beets was determined by actual chemical analysis. This careful method of selection has been in operation for more than forty years, and has resulted in greatly increasing the sugar content in the beets, and has rendered their cultivation profitable where otherwise the industry would have failed.

The second most noteworthy case of increasing certain chemical constituents in a plant by careful breeding is that furnished by the investigations of the Illinois Agricultural Experiment Station in increasing the nitrogen, oil, and starch content in corn. These noteworthy experiments carried out by Doctor Hopkins and his assistants have greatly stimulated breeding work of this nature, and have paved the way for further research of a similar kind.

In wheat it is particularly necessary that a thorough knowledge be obtained of the variations in the chemical constituents and their relation to the other characters of the plant, such as yield, size of kernel, size of head, season of maturity, etc. Doctor Lyon's extensive researches will thus be found very valuable in enabling us to understand more clearly these complex relations and in pointing out the main factors to be considered in breeding wheats to increase the gliadin and glutenin content, and still obtain increased yield and better bread-making qualities.

The gross selection of wheat seed heretofore has largely been based on the separation of large and heavy kernels. Doctor Lyon's researches have demonstrated that the smaller and lighter kernels contain the largest percentage of nitrogen, and that while the yield from kernels of this kind at first gives a smaller yield of grain, the total yield per acre of nitrogen is nevertheless greater. By continuous selection of the smaller and lighter kernels for several generations he shows that the grain yield gradually increases and finally approaches or equals the yield derived from the select large and heavy kernels. This gives us a new view of the process of wheat selection necessary to increase the nitrogen yield per acre.

The very numerous chemical analyses made by Doctor Lyon give an indication of the great variation of the percentage of proteid nitrogen present in different plants. In the analyses of samples in 1902 the plants varied from 2.02 per cent to 4 per cent, while in the analyses of the next year a variation from 1.20 per cent to 5.85 per cent was found. The existence of this wide variation affords abundant opportunity for improvement by selection.

Evidence is also given which shows conclusively that the average composition of a spike of wheat may be judged from the analyses of a row of its spikelets. A satisfactory method of conducting selections has thus been devised.

The results also show that early-maturing plants give much the largest average yield, which is a most important point in guiding selection to increase the yield. The percentage of proteid nitrogen is rather less in the early plants, but the total nitrogen per plant is probably greater.

The quality of the gluten largely determines the bread-making value of a variety of wheat, and it is thus important to keep the ratio of the two elements constituting the gluten—the gliadin and glutenin—the same. Doctor Lyon has shown that as the gluten content is increased by selection the ratio of gliadin to glutenin remains about the same, so that the value of the wheat for bread-making purposes is not impaired.

The extensive data presented in this bulletin bearing on important matters relating to the improvement of wheat by breeding will enable wheat breeders to plan and conduct their operations with a degree of certainty which would otherwise not be possible.

HERBERT J. WEBBER,
Physiologist in Charge of Laboratory of Plant Breeding.

WASHINGTON, D. C., *March 30, 1905.*

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IMPROVING THE QUALITY OF WHEAT.

OBJECT OF THE INVESTIGATION.

Efforts to improve the wheat plant have been numerous and have accomplished important results. The work of Fultz, Clawson, Rudy, Wellman, Powers, Hayne, Bolton, Cobb, Green, and Hays in improving by selection, and of Pringle, Blount, Schindel, Saunders, Farrar, Jones, Carleton, and Hays in improving by hybridization, has resulted in giving this country many prolific strains and varieties of wheat, while Garton Brothers, of England, Farrar, of New South Wales, Vilmorin, of France, Rimpau, of Germany, and others have accomplished the same for other portions of the world. Attempts at improvement have, however, been directed primarily toward effecting an increase in the yield rather than in the quality of the crop. While the latter property has not been entirely lost sight of, selection based on quality has never been applied to the individual plant, but only to the progeny of otherwise desirable plants.

Why selection for quality of grain in the individual plant has not gone hand in hand with selection for other desirable properties is perhaps to be explained by the fact that no method for such selection has ever been devised. Mr. W. Farrar, of Queanbeyen, New South Wales, in an address made a short time ago, said:

> Before we can make any considerable progress in improving the quality of the grain of the wheat plant we shall have to devise a method for making a fairly correct quantitative estimate of the constituents * * * of the grain of a single plant and yet have seeds left to propagate from that plant.

In devising a method for increasing the percentage of nitrogen in wheat it becomes desirable to know the causes that produce variation in this constituent of the kernel. Numerous experiments and observations have been made on this subject, the results of which agree in the main in attributing such variation to the following conditions:

(1) Stage of development of the kernel.
(2) Variation in temperature of different regions.
(3) Variation in temperature of different years in the same region.
(4) Variation in the supply and form of soil nitrogen.
(5) Variation in the supply of soil moisture.

All of these factors have been studied, and are recognized as operative. Nothing, however, appears to have been done to show their influence upon the actual amount of nitrogen taken up by the wheat plant and deposited in the kernel. This is really the point of greatest interest; for although it is desirable to secure a wheat of greater nutritive value, it should not be done at the sacrifice of yield of nitrogenous substance.

Admitting that variation in the nitrogen content of wheat is induced by the conditions mentioned, it is essential to the plant breeder to know whether a high or low nitrogen content may be, under similar conditions, a characteristic of an individual plant; whether this quality is transmitted to the offspring; with what constant characteristics it is correlated, and whether a high percentage of nitrogen in a normal, perfectly matured wheat plant is an indication of a large accumulation of nitrogen by that plant.

The data contained in this paper cover the points mentioned, and it is hoped that some definite information has been gained that will lead to a practical solution of the problem of improving by breeding the quality of wheat for bread making.

PART I.

HISTORICAL.

SOME CONDITIONS AFFECTING THE COMPOSITION AND YIELD OF WHEAT.

Experiments to ascertain the effect of different conditions upon the composition and yield of wheat have been conducted mainly along the following lines:

(1) Stage of growth at which the grain is harvested.
(2) Influence of immature seed upon the resulting crop.
(3) Effect of climate.
(4) Effect of soil.
(5) Effect of soil moisture.
(6) Influence of size or weight of seed upon the resulting crop.
(7) Influence of specific gravity of seed upon the resulting crop.

A brief summary of a number of these experiments is herewith given.

COMPOSITION AS AFFECTED BY TIME OF CUTTING.

In 1879,[a] and again in 1892,[b] Dr. R. C. Kedzie conducted very careful experiments to note the chemical changes that occur in the wheat kernel during its formation and ripening. These agree in the main in showing a gradual decrease in the percentage of total nitrogen, albuminoid nitrogen, and non-albuminoid nitrogen from the time the grain set to the time the kernel was ripe. The decrease in all of these constituents was much more rapid during the first than during the last stages of this development. The percentage of ash decreased at the same time.

In 1897 Prof. G. L. Teller[c] carried on some experiments in which he covered the ground already gone over by Doctor Kedzie and also contributed to the knowledge of the subject some very important data concerning the proportion of the various proteids contained in the wheat kernel during the process of development. Teller found that the proportion of total nitrogen in the dry matter steadily decreased from the time the kernel was formed up to about a week before ripening, but that, unlike Doctor Kedzie's results, it gradually increased from that time on. He intimates that this increase before ripening may have been due to defective sampling and hoped to repeat the experiment to remedy this, but he has published nothing further. The amid nitrogen continued to decrease up to the time of ripening, as did also the ash, fats, fiber, dextrins, and pentosans. There was a gradual and marked increase in the proportion of gliadin up to the time of ripening, and a somewhat less and rather irregular decrease in the proportion of glutenin during the same period.

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[a] Report of Michigan Board of Agriculture, 1881–82, pp. 233–239.

[b] Michigan Agricultural Experiment Station Bulletin 101.

[c] Arkansas Agricultural Experiment Station Bulletin 53.

Failyer and Willard[a] report analyses of wheat in the soft-dough stage and when ripe. The ash, crude fiber, fat, and the total and albuminoid nitrogen were higher in the soft-dough wheat, and the nitrogen-free extract and non-albuminoid nitrogen were higher in the ripe wheat.

Dietrich and König[b] quote results from five experimenters—Reiset, Stockhardt, Heinrich, Nowacki, and Handtke. Only in one case (Heinrich) is there a constant decrease in total nitrogen as the grain approaches ripeness. There is much inconstancy in the results, there being in some cases a decrease in nitrogen between the milk stage and full ripeness and sometimes an increase. There is little information to be gained from the results quoted by Dietrich and König.

Körnicke and Werner in their "Handbuch des Getreidebaues"[c] refer to the work of Stockhardt, and also that of Heinrich, to show that during the process of ripening the percentage of nitrogen in the wheat kernel gradually diminishes, as does also the percentage of ash, and that, on the other hand, the percentage of carbohydrates increases during the same period. Heinrich also shows by a statement of the number of grams of these constituents in 2,600 kernels at different stages of development that the absolute amount of nitrogen and ash increases up to the time of ripening, and that consequently the decrease in the percentage of these constituents is due to the rapid increase in the carbohydrates. The results obtained by Heinrich appear as follows when tabulated:

Stage of growth.	Starch.		Protein.		Ash.	
	Percentage in 100 parts of dry matter of kernel.	Grams in 2,600 kernels.	Percentage in 100 parts of dry matter of kernel.	Grams in 2,600 kernels.	Percentage in 100 parts of dry matter of kernel.	Grams in 2,600 kernels.
14 days after bloom	61.44	22.0	14.05	5.0	2.48	0.84
Beginning to ripen	74.17	58.5	12.21	10.0	2.14	1.70
Ripe	75.66	67.0	11.82	10.5	1.97	1.75
Overripe	76.38	70.0	11.67	10.7	1.88	1.79

Nedokutschajew[d] analyzed wheat kernels at different stages of development and found an almost uniform decrease in the percentage of total nitrogen, a slight but irregular decrease in the percentage of proteid nitrogen in the dry matter, and a constant decrease in the percentage of amid nitrogen. He holds that the amid substances are converted into albumen as the kernels ripen. His figures are as follows:

---

[a] Kansas Agricultural Experiment Station Bulletin 32.

[b] Zusammensetzung u. Verdaulichkeit der Futtermittel, 1, p. 419.

[c] Handbuch des Getreidebaues, Berlin, 1884, 2, pp. 474–476.

[d] Landw. Vers. Stat., 56 (1902), pp. 303–310.

Date.	Weight of kernel (mg.).	Percentage of—				
		Dry matter.	Total nitrogen.	Proteid nitrogen.	Asparagin nitrogen.	Amid nitrogen.
July 13	9.17	30.14	2.87	1.90	0.29	0.68
July 18	15.80	37.23	2.55	1.94	.20	.41
July 24	30.79	45.18	2.65	2.33	.19	.13
July 29	37.99	38.37	2.46	2.08	.16	.22
August 3	46.39	51.52	2.32	1.98	.13	.21
August 9	45.46	49.83	2.37	2.13	.11	.13

Judging from these results there can be no doubt that the percentage of nitrogen, both total and proteid, decreases as the kernel develops, owing to the more rapid deposition of starch that goes on during the later stages of growth. The larger part of the nitrogen used by the wheat plant appears to be absorbed during the early life of the plant. This is transferred in large amounts to the kernel in the early stages of its development, after which nitrogen accretion by the kernel is comparatively slight. The deposition of starch, on the other hand, continues actively during the entire development of the kernel. It would further appear that the amid nitrogen is converted into proteid compounds as development proceeds.

As showing the stages of growth of the wheat plant at which the greatest absorption of nitrogen occurs, some experiments may be quoted.

Lawes and Gilbert[a] say:

> In 1884 we took samples of a growing wheat crop at different stages of its progress, commencing on June 21, and determind the dry matter, ash, and nitrogen in them. Calculation of the results showed that, while during little more than five weeks from June 21 there was comparatively little increase in the amount of nitrogen accumulated over a given area, more than half the total carbon of the crop was accumulated during that period.

Snyder's analyses[b] show that of the total amount of nitrogen taken up by the wheat plant, 85.97 per cent is removed from the soil within fifty days after coming up, 88.6 per cent by time of heading out, and 95.4 per cent by the time the kernels are in the milk.

Adorjan[c] finds that assimilation of plant food from the soil is not proportional to the formation of dry matter in the plant, but that it proceeds more rapidly in the early stages of growth. During early growth nitrogen is the principal requirement. The nitrogen stored up at that time is, he says, used later for the development of the grain.

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[a] On the Composition of the Ash of Wheat Grain and Wheat Straw, London, 1884.

[b] Minnesota Experiment Station Bulletin 29, pp. 152–160.

[c] Abstract, Experiment Station Record, 14, p. 436, from Jour. Landw., 50 (1902), pp. 193–230.

It is too well known to require substantiation by experimental evidence that the yield of grain per acre and the weight of the individual kernel increase as the grain approaches ripeness. It is therefore quite evident that immaturity, although resulting in a higher percentage of nitrogen in the wheat kernel, would curtail the production of nitrogen by the crop, and, furthermore, that the production of proteids would be still further lessened by reason of the greater proportion of amid substances present in the grain at that time.

INFLUENCE OF IMMATURE SEED UPON YIELD.

Georgeson[a] selected kernels from wheat plants that were fully ripe, and from plants cut while the grain was in the milk. He seeded these at the same rate on 2 one-tenth acre plots of land. The immature seed yielded at the rate of 19.75 bushels per acre of grain and 0.8 ton of straw, while the mature seed produced 22 bushels of grain and 1.04 tons of straw per acre. Georgeson says that in a similar experiment the previous year the difference in favor of the mature seed was still more pronounced.

Although the evidence is limited, it may safely be considered that the use of immature seed will result in a smaller yield of wheat than if fully ripe seed be used.

INFLUENCE OF CLIMATE UPON COMPOSITION AND YIELD.

Lawes and Gilbert[b] state that "high maturation in the wheat crop as indicated by the proportion of dressed corn in total corn, proportion of corn in total product (grain and straw), and heavy weight of grain per bushel, is, other things being equal, generally associated with a high percentage of dry substance and a low percentage of both mineral and nitrogenous constituents." This is based upon the wheat crops at Rothamsted for the years 1845 to 1854, inclusive.

More recent publications[c] by these investigators reaffirm their belief that the composition of the wheat kernel depends more largely upon the conditions that affect its degree of development than upon any other factor. They found almost invariably that a season that favored a long and continuous growth of the plant after heading, resulting in a large yield of grain, a high weight per bushel, and a plump kernel, produced a kernel of low nitrogen content.

[a] Abstract, Experiment Station Record, 4, p. 407, from Kansas Experiment Station Bulletin 33, p. 50.

[b] On Some Points in the Composition of Wheat Grain, London, 1857.

[c] Our Climate and Our Wheat Crops, London, 1880, and On the Composition of the Ash of Wheat Grain and Wheat Straw, London, 1884.

Körnicke and Werner[a] cite an experiment in which winter wheat grown in Poppelsdorf for several years was sent to and grown in the moist climate of Great Britain, in Germany, and in the continental climate of Russia (steppes). The results were as follows:

Locality.	Number of experiments.	Weight (in grams) of—		Percentage of—	
		100 plants.	Kernels from 100 plants.	Grain.	Straw.
Great Britain	37	600	227	37.8	62.3
Germany	18	500	204	40.8	59.2
Southern Russia	19	365	160	44.0	56.0

These investigators conclude from the results that in a moist climate relatively more straw and less grain are produced than in a dry, warm climate. The thickness of the straw and the weight of the kernels from 100 heads are greater, while the percentage by weight of kernels to straw is much less in a moist climate. They also quote Haberlandt as saying that a continental climate produces a small, hard wheat kernel, rich in gluten and of especially heavy weight.

Dehérain and Dupont[b] report some interesting observations as to the effect of climate on the composition of wheat. They state that the harvest of 1888 at Grignon was late and the process of ripening slow. There was a heavy yield of grain having a gluten content of 12.60 per cent and a starch content of 77.2 per cent. The following season was dry and hot, with a rapid ripening of the grain, resulting in a smaller crop. The gluten content of the grain was 15.3 per cent and the starch content 61.9 per cent. They removed the heads from a number of plants. The next day the stems were harvested, as were also an equal number of entire plants. The stems without heads showed that carbohydrates equal to 5.94 per cent of the dry matter had been formed. The stems on which the heads remained one day longer contained 1.63 per cent carbohydrates. They argue from this that the upper portion of the stem, provided it is still green, performs the functions of the leaves in other plants and thus elaborates the starch that fills out the kernel in its later development.

A report from the Ploti Experiment Station[c] states that the conditions that favored an increase in yield caused a reduction in the relative proportion of nitrogen in the grain. Excessive humidity favored the process of assimilation of carbohydrates, while drought hastened maturation and produced a grain relatively rich in proteids.

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[a] Handbuch des Getreidebaues, Berlin, 1884, pp. 69, 70.

[b] Ann. Agron., 1902, p. 522.

[c] Abstract, Experiment Station Record, 14, p. 340, from Sept. Rap. An. Sta. Expt. Agron. Ploty, 1901, pp. xiv–180.

Wiley[a] sent wheat of the same origin to California, Kentucky, Maryland, and Missouri. The original grain and the product from each State were analyzed. The results of one year's test were reported. Regarding the effect of climate, he says:

> There appears to be a marked relation between the content of protein matter and starch and the length of the growing season. The shorter the period of growth and the cooler the climate the larger the content of protein and the smaller the content of starch, and vice versa.

Shindler,[b] in his book upon this subject, says (p. 75):

> With the length of the growing period, especially with the length of the interval between bloom and ripeness, varies not only the size of the kernel, but also the relative amount of carbohydrates and protein it contains.

Again, on page 76, Shindler says:

> All this shows that the protein constituent of the kernel depends in the first place upon the length of the growing period and next upon the richness of the soil.

Melikov[c] made analyses of different varieties of wheat of the crops of the years 1885–1899 grown in southern Russia. The protein varied in different years from 14 to 21.2 per cent. Melikov concludes that the nitrogen content is highest in dry years and lowest in years of larger rainfall, in which years the yield of wheat per acre is also greater.

Gurney and Morris,[d] in one of their reports, say:

> This increased gluten [over previous years] is probably largely due to differences in the seasons, the weather being hot and dry while the grain was ripening, since it is characteristic not of these wheats alone but of most of the grain grown in the colony.

The conclusion to be inevitably derived from these observations is that climate is a potent factor in determining the yield and composition of the wheat crop, and, further, that its effect is produced by lengthening or shortening the growing season, particularly that portion of it during which the kernel is developing. A moderately cool season, with a liberal supply of moisture, has the effect of prolonging the period during which the kernel is developing, thus favoring its filling out with starch, the deposition of which is much greater at that time than is that of nitrogenous material. With this goes an increase in volume weight and an increased yield of grain per acre. On the other hand, a hot, dry season shortens the period of kernel development, curtails the deposition of starch, leaving the percentage of nitrogen relatively higher, and gives a grain of lighter weight per bushel and smaller yield per acre.

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[a] Yearbook U. S. Department of Agriculture, 1901, pp. 299–308.

[b] Der Weizen in seinem Beziehungen zum Klima und das Gesetz der Korrelation, Berlin, 1893.

[c] Abstract, Experiment Station Record, 13 p. 451, from Zhur. Opuitn. Agron., 1 (1900), pp. 256–267.

[d] Agricultural Gazette of New South Wales, 12, pt. 2, pp. 1403–1424.

The fact that one variety of wheat is adapted to a hot, dry climate and another to a cool, moist one does not mean that the former undergoes as complete maturation as the latter, even though the grain is not shriveled. This is shown by the fact that a variety of wheat well adapted to a hot, dry climate will, when planted in a cool, moist one, immediately grow plumper and the kernel weight will increase, as was the case in the experiment of taking Minnesota wheats to Maine.

INFLUENCE OF SOIL UPON COMPOSITION AND YIELD.

In considering the effect of the soil upon the wheat crop there will naturally be included experiments designed to show the effect of fertilizers upon the crops. It is, in fact, upon experiments with fertilizers that we must depend for most of our information on this subject.

Experiments to ascertain the effect of fertilizers upon the composition of the wheat kernel were conducted by Lawes and Gilbert for a period of years extending from 1845 to 1854.[a] Plots of land in which wheat was grown continually were treated annually as follows: Unmanured, manured with ammoniacal fertilizer alone, and manured with ammoniacal fertilizer and proportionate amounts of mineral salts. In composition calculated to dry matter, the wheat on the plots receiving ammoniacal fertilizer alone contained quite uniformly a slightly larger amount of nitrogen than either of the other two. The averages for the ten years were as follows:

Kind of fertilizer, if any.	Percentage of—		Weight of grain per bushel (pounds).	Percentage of good kernels.	Yield per acre (pounds).
	Nitrogen in dry matter.	Ash in dry matter.			
Unmanured	2.13	2.07	58.51	90.6	1,045
Ammonium salts	2.26	1.85	58.9	90.3	1,668
Minerals and ammonium salts	2.22	1.96	60.2	92.8	1,969

There was practically no difference in the nitrogen content of the straw. From these experiments the authors quoted conclude that there is no evidence that the nitrogen content of the wheat kernel can be increased at pleasure by the use of nitrogenous manures.

Ritthausen and Pott[b] report an experiment in which plots of land were manured (1) with superphosphate alone, (2) with nitrate alone, (3) with a mixture of superphosphate and nitrate, and (4) were left unmanured. There were three plots of each. The following is a tabulated statement of their results:

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[a] On Some Points in the Composition of Wheat Grain, London, 1857.

[b] Landw. Vers. Stat., 16 (1873), pp. 384–399.

Kind of fertilizer, if any.	Weight of 52 c. c. of kernels (grams).	Yield of grain on plot (kilos).	Percentage of nitrogen in dry matter.
Unfertilized	1,306	....	2.60
Superphosphate	1,339	2.72	3.49
Nitrate	1,413	2.30	3.43
Superphosphate and nitrate	1,451	2.03	3.62

It will be noticed that the effect of the nitrate fertilizer was to decrease the yield of grain, but to increase the size of the kernel and its content of nitrogen.

Wolff,[a] as early as 1856, in summing up the experiments of Hermbstadt, Muller, and John with barley, and of Lawes and Gilbert with wheat, says:

> In the presence of a sufficient amount of phosphoric acid and alkali the effect of manuring with an easily soluble nitrogen compound is an improvement in the grain both in quantity and quality [meaning plumper kernels]. The kernels decrease in percentage of nitrogen, but become plumper, become absolutely and relatively richer in starch, and have a better appearance and a higher commercial value. But when the nitrogenous food in the soil exceeds a certain relation to the temperature and rainfall the quality of the grain becomes poorer [harder], it becomes lighter and smaller, takes on a darker color, and generally becomes richer in percentage of nitrogen in the air-dry substance.

Von Gohren[b] also reports results of experiments in fertilizing wheat. All experiments were apparently made in the same year. He grew the crop on six different plots of land, five of which were manured and each with a different fertilizer. In the crop he distinguished between large kernels and small kernels to show the quality of the product. Determinations of proteids and starch were made, and these were calculated to the yield of each constituent on each plot.

The following table shows the yield of each of the characters determined, and compares those raised on the unmanured plot with those on the manured ones by taking the former as one and reducing the others to the corresponding figure:

Yield and percentage.	Unfertilized.	Ashes.	Oil cake.	Bat guano.	Oil cake and ashes.	Peruvian guano.
Yield of grain	1.000	1.011	1.071	1.143	1.215	1.286
Yield of large kernels	1.000	.146	1.928	2.552	2.226	2.786
Yield of small kernels	1.000	.953	.704	.538	.781	.642
Yield of proteids	1.000	.999	.915	.936	1.070	1.114
Yield of starch	1.000	1.009	1.081	1.174	1.264	1.303
Percentage of proteids	14.42	14.25	12.70	11.81	12.70	13.22
Percentage of starch	62.67	62.56	63.25	64.41	65.24	63.55

The results show an increased yield from the use of fertilizers, the production increasing with the application of complete manures.

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[a] Die naturgesetzlichen Grundlagen des Ackerbaues, Leipzig, 1856, p. 774.

[b] Landw. Vers. Stat., 6 (1864), pp. 15–19.

The yield of grain of good quality increases in the same way, and the yield of grain of poor quality decreases proportionately. It must be remembered that by good quality of grain in these early writings is meant plump kernels and not necessarily what would be considered wheat of good milling quality at the present day. The production of proteids per acre decreased with the use of the incomplete fertilizers, ashes and oil cake, and even with the bat guano. It increased, however, with the use of oil cake and ashes combined and of Peruvian guano. The percentage of proteids was greatest in the unfertilized grain and the percentage of starch least, with the exception of one fertilized plot.

The very evident effect of the fertilizers in this case was to produce a more completely matured kernel. It will be noticed that the plots producing grain of highest starch content were those having the greatest proportion of plump kernels.

Again, in 1884, Lawes and Gilbert[a] report results obtained from manured and unmanured soils. These experiments cover a period of sixteen years and are divided into two periods of eight years each. In one of these periods the seasons were favorable for wheat, in the other unfavorable.

Character.	Favorable seasons.			Unfavorable seasons.		
	Barnyard manure.	Unmanured.	Ammonium salts alone.	Barnyard manure.	Unmanured.	Ammonium salts alone.
Weight of grain per bushel (pounds)	62.6	60.5	60.4	57.4	54.3	53.7
Percentage of grain to straw	62.5	67.4	66.2	54.5	51.1	46.7
Grain per acre (pounds)	2,342.0	1,156.0	1,967.0	1,967.0	823.0	1,147.0
Straw per acre (pounds)	6,089.0	2,872.0	4,774.0	5,574.0	2,433.0	3,601.0
Percentage of nitrogen in dry matter	1.73	1.84	2.09	1.96	1.98	2.25
Percentage of ash in dry matter	1.98	1.96	1.74	2.06	2.08	1.91
Nitrogen per bushel (pounds)	1.083	1.113	1.262	1.125	1.075	1.208

It is evident from this statement that the largest crops and best developed kernels were obtained from the soils treated with barnyard manure, and that these kernels contained the lowest percentage of nitrogen. The crops on unmanured soil stood next in these respects, except in yield. Those on the soil receiving ammonium salts produced the most poorly developed kernels and those of highest nitrogen content, but gave larger yields than the unmanured soil.

In the unmanured soil there was a very evident lack of plant food, as indicated by the light crops. The effect upon the kernel was to curtail its development, leaving it of light weight and with a relatively high nitrogen content.

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[a] On the Composition of the Ash of Wheat Grain and Wheat Straw, London, 1884.

Hermbstadt obtained some curious results, as quoted by D. G. F. MacDonald,[a] as follows:

He sowed equal quantities of wheat upon the same ground and manured them with equal weights of the different manures set forth below. From 100 parts of each sample of grain produced he obtained starch and gluten in the following proportions:

Kind of fertilizer, if any.	Gluten.	Starch.	Produce.
Unfertilized	9.2	66.7	Threefold.
Potato peels	9.6	65.94	Fivefold.
Cow dung	12.0	62.3	Sevenfold.
Pigeon dung	12.2	63.2	Ninefold.
Horse dung	13.7	61.64	Tenfold.
Goat dung	32.9	42.4	Twelvefold.
Sheep dung	32.9	42.8	Do.
Dried night soil	33.14	41.44	Fourteenfold.
Dried ox blood	34.24	41.43	Do.
Dried human urine	31.1	39.3	Twelvefold.

These results are not to be considered seriously, representing as they do an impossible condition.

Prof. H. A. Huston[b] treated 0.01-acre plots of land each with nitrate of soda, dried blood, sulphate of ammonia, rotted stable manure, and muck, respectively, either in the autumn or spring, or in both seasons. In 1891 all the plots treated with nitrogenous compounds showed marked increase in the percentage of nitrogen in the grain. In 1892 the results were by no means so uniform and would not justify the conclusion that nitrogenous fertilizers increased the nitrogen content of the wheat.

Vignon and Couturier[c] tested the effect of phosphate fertilizer alone upon the nitrogen content of the grain of two varieties of wheat. On Plot 1 they used 75 kilograms of phosphoric acid per hectare; on Plot 2, 150 kilograms, and on Plot 3, 225 kilograms.

Variety.	Percentage of nitrogen in grain.		
	Plot 1.	Plot 2.	Plot 3.
Goldendrop	1.83	1.61	1.54
Riéte	2.07	1.98	1.82

There was a very evident decrease in the nitrogen content of the crop as the quantity of fertilizer was increased.

It was concluded from experiments conducted at the Ploti Experiment Station[d] that, with favorable meteorological conditions, manure increased the total amount of nitrogen taken up by wheat, but, although it thus increased the total production of nitrogen, it decreased the relative proportion of nitrogenous substance.

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[a] Practical Hints on Farming, London, 1868.

[b] Indiana Experiment Station Bulletins 41 and 45.

[c] Compt. Rend., 132 (1901), p. 791.

[d] Abstract, Experiment Station Record, 14, p. 340, from Sept. Rap. An. Sta. Expt. Agron. Ploty, 1901, pp. xiv–180.

Bogdau[a] conducted investigations the results of which indicated that with an increase in the soluble salt content of 22 alkali soils the nitrogen and ash contents of the wheat kernels increased, but the absolute weight of the kernels diminished. These soluble salts are rich in nitrates.

Experiments were conducted by Whitson, Wells, and Vivian[b] in which plants were grown in pots the soils of which were in some cases fertilized with nitrates and in others with leachings of single and of double strengths from fertile soils. Field experiments were conducted on manured and unmanured plots. All of the analyses, except in the case of oats, were of the whole plant. Of the ripe oat kernels those from the unfertilized soil contained 2.57 per cent of nitrogen, while the average of those from the fertilized soil was 2.78 per cent.

Guthrie[c] conducted experiments with fertilizers for wheat during two years, in which he kept a record of the yield and gluten content of the grain. The following is a statement of the results:

Kind of fertilizer, if any.	Experiments in 1901—				Experiments in 1902, at Wagga.	
	At Wagga.		At Bathurst.			
	Yield per acre (bushels).	Percentage of gluten.	Yield per acre (bushels).	Percentage of gluten.	Yield per acre (bushels).	Percentage of gluten.
None	7.7	11.99	13	11.80	17.6	9.8
Ammonium sulphate	8.7	10.43	16	11.21	17.6	8.7
Superphosphate	13.3	12.06	13.5	12.01	22.6	11.4
Potassium sulphate	13.0	12.02	13.0	11.29	19.2	10.0
Ammonium sulphate, superphosphate, potassium sulphate	10.0	11.70	13.7	12.05	20.3	12.0

In this experiment there was in each case a higher percentage of gluten in the wheat raised on the fertilized soil than in that from the soil fertilized with ammonium sulphate, and in the latter less than in the grain fertilized with other material.

The most striking feature of these results is their apparent lack of uniformity. In some cases the use of nitrogenous fertilizers was accompanied by an increase in the nitrogen content of the grain and in other cases no increase appeared; in some cases phosphoric acid fertilizers apparently increased the nitrogen content and in others they did not have this effect.

Climatic influences have doubtless operated largely in these results, but they are not considered by any of the experimenters except Wolff.

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[a] Abstract, Experiment Station Record, 13, p. 329, from Report of Department of Agriculture, St. Petersburg, 1900.

[b] Wisconsin Experiment Station Report, 19 (1902), pp. 192–209.

[c] Agricultural Gazette of New South Wales, 13 (1902), No. 6, p. 664; and No. 7, p. 728.

It is evident that in all experiments with depleted soils the plants on the plots receiving complete fertilizers would take up larger amounts of plant food, including nitrogen, than would plants on unmanured soils. Any conditions that would prevent the normal ripening of the crop on both soils would therefore leave a higher percentage of nitrogen in the plants upon the unmanured soil. On the other hand, under conditions which would permit of a complete maturation of the crop there might be no difference in the composition of the grain from the manured and unmanured soils. It is evident, however, that the production of both nitrogen and starch in pounds per acre would be greater on the manured soils.

Another condition that may affect the results is the arrested development of kernels on unmanured soils that are seriously depleted of plant food. Such depletion may interfere with complete maturation of the crop while the crop on the manured soil will mature fully. In consequence the grain on the unmanured soil will contain a higher percentage of nitrogen but a smaller yield per acre. The use of a nitrogenous manure alone on exhausted soils may likewise result in a grain of higher nitrogen content.

Expressed in a more general way, this means that wheat of the same variety grown under the same climatic conditions will have approximately the same percentage of nitrogen if allowed to mature fully, but any permanent interruption in the process of maturation will result in a higher percentage of nitrogen, and in the latter case the percentage of nitrogen will depend upon the stage at which development was interrupted, and also upon the amount of nitrogen accumulated by the plant, that being greater on soils manured with nitrogenous fertilizers alone than on exhausted soils, and greater on soils receiving complete manures than on exhausted soils receiving only nitrogenous fertilizers, provided the stage at which development ceased be the same in both cases. It thus happens that wheat growing on the soil allowing it to absorb the largest amount of nitrogen will, other things being equal, have a higher nitrogen content if the development of the kernel be permanently checked, although if it were allowed to mature fully it would not have a greater percentage of nitrogen than that grown on the soil affording less nitrogen.

Reviewing the experiments, we find that in Lawes and Gilbert's first experiment the percentage of nitrogen in the unmanured soil was less than on the soil receiving only nitrogenous fertilizer, and that the weight of grain per bushel and the percentage of good kernels on the two plots were practically the same. It would not appear, therefore, that the wheat on the plot receiving the nitrogenous fertilizer was less well matured than that on the unmanured plot. In this case there appears to be a slight increase in the percentage of nitrogen, due entirely to the use of nitrogenous fertilizers. Comparing the grain on the plot receiving only nitrogenous fertilizer with that receiving the complete fertilizer it will be seen that the former has a higher percentage of nitrogen, but this is evidently due to the poorly developed kernels which weigh less per bushel than the grain on the completely fertilized plot.

Von Gohren's results show plainly that the kernels on the manured land developed better than on the unmanured, and with this better development there was an increase in the percentage of starch and a decrease in the nitrogen.

In Lawes and Gilbert's second experiment the percentage of nitrogen in the wheat on the soil manured with ammonium salts was less than that in the wheat on the unmanured soil, but the weight of grain per bushel shows that the higher nitrogen content was due, in part at least, to incomplete maturation. The higher percentage of nitrogen in the wheat on the soil receiving only nitrogenous manures as compared with that receiving complete manures can be traced to the same condition of the grain.

INFLUENCE OF SOIL MOISTURE UPON COMPOSITION AND YIELD.

Experiments were conducted by D. Prianishinkov[a] in which wheat was raised with different degrees of moisture, but in the same soil and under the same conditions of light and temperature. With a larger amount of moisture in the soil there was a lower nitrogen content in the grain. It was also stated that the duration of the period of vegetation was somewhat shorter when the moisture supply was greater.

Traphagen[b] reports marked changes in the composition of wheat grown with and without irrigation at the Montana Experiment Station. A wheat grown under irrigation on the station farm was planted the following year on land not irrigated. Presumably the land was of similar character. The two crops of grain were analyzed and the percentages stated below were found.

Crop.	Moisture.	Crude protein.	Ether extract.	Nitrogen-free extract.	Crude fiber.	Ash.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Irrigated wheat	7.87	8.81	1.93	76.99	2.60	1.80
Unirrigated wheat	7.65	14.41	2.23	71.33	2.65	1.70

No records of yields or of weights of kernels are given, but it is fair to suppose that the unirrigated wheat possessed the light, shrunken kernel which is characteristic of wheat raised without sufficient moisture.

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[a] Abstract, Experiment Station Record, 13, p. 631, from Zhur. Opuitn. Agron., 1 (1900), No. 1, pp. 13–20.

[b] Montana Experiment Station Report (1902), pp. 59–60.

Irrigation experiments were conducted by Widtsoe[a] in which wheat of the same variety was raised on plots of land each one of which received a different quantity of water. A record was kept of the yield and composition of the grain on each plot.

Plot.	Water applied (inches).	Yield per acre (bushels).	Percentage of—		Yield (in pounds) per acre of—	
			Protein in grain.	Ash in grain.	Nitrogen.	Ash.
317	4.63	4.50	24.8	2.50	10.7	6.75
319	5.14	3.83	23.2	3.07	8.5	7.05
320	8.73	10.33	19.9	2.54	19.7	15.74
318	8.89	11.33	19.4	2.93	21.1	19.72
321	10.30	14.66	18.4	2.34	25.9	20.24
325	12.09	11.16	21.3	3.25	22.8	21.44
322	12.18	11.66	23.1	2.88	25.8	20.30
326	12.80	13.00	17.1	2.52	21.3	21.50
327	17.50	15.33	17.2	2.57	25.3	23.64
328	21.11	17.33	15.9	2.34	26.4	24.33
329	30.00	26.66	14.0	4.14	35.8	66.20
330	40.00	14.50	17.1	2.52	23.8	21.92

The results show that with an increase in the water used for irrigation up to 30 inches there were in general an increase in the yield of grain and a decrease in the nitrogen content. No volume weights or other means of judging of the development of the kernels on the different plots are given, but there is no reason to suppose that the grain on the plots receiving small quantities of water was not poorly developed. The column added showing the yield of nitrogen in pounds per acre indicates a lack of nutriment in the grain on these plots.[b]

High nitrogen content arising from a small supply of soil moisture is sometimes due to a restricted development of the kernel. There is nothing in these results to indicate a greater absorption of nitrogen by the crop on soil having less moisture, but results of this nature are cited elsewhere in this bulletin.

INFLUENCE OF SIZE OR WEIGHT OF THE SEED-WHEAT KERNEL UPON THE CROP YIELD.

Sanborn[c] reports experiments to ascertain the effect of separating seed wheat into kernels of different grades to ascertain the effect upon the yield. He divided the kernels into large, medium, small, ordinary (grain as it came from the thrasher), and shriveled, and continued the experiments for four years. Apparently the large kernels were separated from the crop grown from large seed the previous year, and so with the other classes of kernels. He tabulates his results as follows:

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[a] Utah Experiment Station Bulletin 80.

[b] Nitrogen has been calculated from proteids by dividing by 6.25.

[c] Utah Experiment Station Report, 1893, p. 168.

Kind of seed.	Yield of grain on plots (in pounds).				Average for 4 years.
	1890.	1891.	1892.	1893.	Bushels per acre.
Large	88.5	72.5	111	63.0	18.72
Medium	....	70.0	87	67.0	16.60
Small	94.0	105.0	64	74.0	18.72
Ordinary	84.0	95.0	87	29.5	16.42
Shriveled	....	43.0	78	31.0	11.25

The relation between yields of the crops representing different sized kernels is so irregular from year to year that suspicion is aroused regarding the accuracy of the results, due to lack of uniformity in soil. Sanborn's conclusion is that very little, if any, advantage is to be gained by separating seed wheat and planting the large kernels.

At the Indiana Experiment Station, Latta[a] conducted experiments in which wheat was separated by means of a fanning mill into heavy and light kernels, but impurities and chaffy seed were fanned out of each lot of wheat. The experiments were continued three years, but the separations were made each year from seed that had not been so separated the year before. The average gain from the large seed for three years was 2.5 bushels per acre.

Georgeson,[b] at the Kansas station, seeded plots of land with (1) light seed weighing 56 pounds per bushel, (2) common seed weighing 62.5 pounds, (3) heavy seed weighing 63 pounds, and (4) selected seed, obtained by picking the largest and finest heads in the field just before the crop was cut, weighing 61.5 pounds per bushel. Seed was separated each year from wheat not grown from previously selected seed. The average results for three years were as follows:

Grade of seed.	Yield of grain per acre (bushels).	Grade of seed.	Yield of grain per acre (bushels).
Light	25.19	Heavy	27.07
Common	26.57	Select (average for 2 years)	25.82

Desprez[c] reports experiments extending through three years in which large kernels were selected from a crop grown from large seed for several years and small seed from a crop grown from small seed for several years. Five varieties of wheat were used. The average results for three years were a difference of 1,067 to 1,828 kilograms of grain per hectare in favor of the large seed, but the difference was in general greater the first year than later. The use of large seed gave a crop with kernels larger than those grown from small seed.

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[a] Indiana Experiment Station Bulletin 36, pp. 110–128.

[b] Kansas Experiment Station Bulletin 40, pp. 51–62.

[c] Abstract, Experiment Station Record, 7, p. 679, from Jour. Agr. Prat., 59 (1895), 2, pp. 694–698.

Middleton[a] reports the yields obtained from large wheat kernels to be almost double those obtained from small seed kernels.

Bolley,[b] as the results of experiments continuing for four years in which plump kernels of large size and plump kernels of small size were selected for seed, concludes that "perfect grains of large size and greatest weight produce better plants than perfect grains of small size and light weight, even when the grains come from the same head."

At the Ontario Agricultural College, Zavitz[c] selected large plump seed, small plump seed, and shrunken seed of both spring and winter wheat. Experiments were continued for eight years with spring wheat and five years with winter wheat, the selections each year being from a crop grown from previously unselected seed. His results are as follows:

Kind of seed.	Yield per acre (in bushels).	
	Spring wheat.	Winter wheat.
Large, plump	21.7	42.4
Small, plump	18.0	34.8
Shrunken	16.7	33.7

Dehérain and Dupont[d] report that the yields from small and large kernels of a number of varieties of wheat were in all cases in favor of the large kernels, but a large difference in yield was obtained only when there was a marked difference in the weight of the kernels.

Soule and Vanatter[e] conducted experiments for three years in which large and small kernels were separated by means of sieves. In addition a plot of unselected seed was planted. The large seed was, each year after the first, selected from the crop grown from large seed the previous year. The same was true of the small seed. These investigators say:

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[a] Abstract, Experiment Station Record, 12, p. 441, from Univ. Coll. of Wales Rept., 1899, pp. 68–70.

[b] North Dakota Experiment Station Report, 1901, p. 30.

[c] Ontario Agricultural College and Experiment Farm Report, 1901, p. 84.

[d] Abstract, Experiment Station Record, 15, p. 672, from Compt. Rend., 135 (1902), p. 654.

[e] Tennessee Experiment Station Bulletin, vol. 16, No. 4, p. 77.

The average difference in yield at the end of three years between large grains (607 per ounce), commercial sample (689 per ounce), and small grains (882 per ounce), with Mediterranean wheat, was 2.06 bushels in favor of large grains as compared with the commercial sample, and 5.18 bushels in favor of large grains over small grains. The difference in yield between the large grains and the commercial sample chiefly occurred the first year; but it is possible, though hardly probable, that the difference was partly due to variation in the soil. The experiment has been carried on in different parts of the field for the last two years, and the difference in yield is now only 0.32 bushel per acre in favor of the large grains.

Cobb[a] reports tests of various grades of wheat kernels with respect to size, and concludes that large kernels give better yields of grain. The seed of one year was not the product of the corresponding grade of the previous one.

Grenfell[b] selected plump and shriveled kernels from the same bulk of grain. Of these 150 kernels were sown in each row, with rows of plump and shriveled kernels alternating. The germination in both rows appeared much alike, but the plants in the rows sown from plump grain soon began to gain on the others and kept ahead for the remainder of the season. The tillering was better in the plump-grain plants. Grenfell tabulates his results thus:

Variety.	Kind.	Percentage of plants that grew.	Number of heads.	Tillering power.	Average yield per acre (bushels).
Steinwedel	Plump	96.0	179	1.24	10.9
Do	Shriveled	89.3	174	1.29	9.9
Purple Straw	do	89.3	153	1.14	6.1
Do	Plump	90.0	200	1.49	10
Do	Shriveled	76.0	140	1.16	6.9
Do	Plump	92.0	161	1.23	8.4
Do	Shriveled	98.0	155	1.34	7.2
Plump-kernel averages		92.7	180	1.32	9.8
Shriveled-kernel averages		88.5	155	1.23	7.5

As bearing upon this subject some experiments conducted by Rünker[c] are of interest. He weighed each of the kernels of a large number of heads of wheat of the Spalding Prolific and Martin Amber varieties, and found that the heaviest kernels occur in the lower half of the spike. With spikes of different lengths and weights, the weight of the average kernel increases with the size of the spike.

Weights of individual kernels from the same spikes show that there is a great range in this respect. One spike, of which Rünker gives the weights of all the kernels, and which is given as representative of the average, shows kernels varying in weight from 36 to 71 milligrams.

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[a] Agricultural Gazette of New South Wales, 14 (1903), No. 2, pp. 145–169.

[b] Agricultural Gazette of New South Wales, 12 (1901), No. 9, pp. 1053–1062.

[c] Jour. f. Landw., 38 (1890), p. 309.

It is therefore quite evident that a sample of wheat taken from spikes of different sizes when separated into lots of light and heavy kernels would have both the larger spikes and smaller spikes represented in each lot of kernels, but doubtless the proportion of kernels from large heads would be greater in the lot of heavy kernels.

It would appear from these results that the evidence was overwhelmingly in favor of large or heavy wheat kernels for seed. Most of the experimenters selected seed of different kinds each year without reference to previous selection. If large seed or small seed represent plants of different characteristics and if these properties are hereditary, the results of selection of large or small seeds for several years may be quite different from what they would be the first year. It is only those experiments in which selection of the same kind of seed has been continued for several generations that may be relied upon to indicate the value of continuous selection of large kernels for seed.

Such experiments have been conducted by Sanborn, by Desprez, and by Soule and Vanatter. The work of Desprez indicates that the size of the kernel is a hereditary quality. That being the case, it is evident that the small seed of the first separation may be composed partly of seed that is small on account of immaturity and partly of seed that is small by inheritance, but which is perfectly normal. When such seed is planted the immature seed will be largely eliminated in the crop, but the naturally small seed will have reproduced itself and will compose most of the crop. When the seed is again separated a much smaller percentage of small seed will be immature, and in consequence a larger number of kernels will produce plants. It would appear from Desprez's experiments, however, that those plants producing small kernels are not so prolific as those producing large kernels.

Sanborn's results make a very good showing for the small kernels, but, as before stated, the extreme irregularity would lead to the belief that the soil on the plots lacked uniformity, or that some other errors had influenced the results. To offset this the tests cover a period of four years, which should help to rectify mistakes, and in consequence the good showing made by the small kernels is entitled to some consideration.

Soule and Vanatter's results fulfill exactly the conditions of the hypothesis that the small seed would the first year contain a much larger proportion of immature kernels than it would in subsequent years, and hence yield more poorly the first year. Their results with heavy kernels as compared with ordinary seed offer little encouragement to the continuous selection of large kernels.

The fact before referred to that both large and small kernels are found on the same head of wheat is perhaps an argument against the superior value of large seed. If the plant and not the seed is the unit of reproduction, small seed from a plant whose kernels averaged large size may be better than large seed from a plant whose kernels averaged small size.

On the other hand, there can be no doubt that the majority of the kernels in the lot of heavy kernels would be from plants having large spikes, and vice versa. This would give the kernels in the heavy lot some advantage. Again, the advantage that the large kernel is supposed to possess for seed may not be in producing a large kernel in the resulting crop, but in giving the plant a better start in life, or producing a more vigorous plant.

RELATION OF SIZE OF KERNEL TO NITROGEN CONTENT.

Richardson[a] has made a large number of analyses of wheats from different parts of the United States. The weight of 100 kernels was also determined in each sample. There can not be said to be any constant relation between the nitrogen content and the kernel weight, but in the main the large kernels have a lower percentage of nitrogen than the small kernels, and inversely.

Pagnoul[b] reports that in a test of eleven varieties of wheat there was in the main a decrease in the percentage of nitrogen in the crop as compared with the seed when there was an increase in the weight of 1,000 kernels in the crop as compared with the seed.

The same investigator[c] again states that in an examination of seventy varieties of wheat there was no constant relation between the size of the kernels and their nitrogen content, but that in general the varieties with small kernels were the varieties richest in nitrogen.

Marek[d] separated wheat of the same variety into lots of large and of small kernels. He found on analysis that the large kernels contained 12.52 per cent protein and the small kernels 13.55 per cent protein.

Woods and Merrill[e] made analyses of a number of wheats grown in Minnesota and of the same varieties grown in Maine. The wheats uniformly developed a larger kernel when grown in Maine. Grouping five varieties raised in Minnesota and five raised in Maine, it will be seen that with this increase in the size of the kernel there was a decrease in the nitrogen content. The analyses, reduced to a water-free basis, are as follows:

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[a] U. S. Department of Agriculture, Division of Chemistry, Bulletins 1 and 3.

[b] Abstract in Centrlb. f. Agr. Chem., 1893, p. 616, from Ann. Agron., 1892, p. 486.

[c] Abstract in Centrlb. f. Agr. Chem., 1888, p. 767, from Ann. Agron., 14, pp. 262–272.

[d] Abstract in Centrlb. f. Agr. Chem., 1876, from Landw. Zeitung f. Westfalen u. Lippe, 1875, p. 362.

[e] Maine Experiment Station Bulletin 97.

Where grown.	Weight of 100 kernels (grams).	Percentage of protein.
Minnesota	2.239	16.22
Maine	3.109	15.43

In a review of the experiments concerning the relation of weight to composition of cereals, Gwallig[a] says that the results obtained by Marek, Wollny, Märcker, Hoffmeister, and Nothwang divide barley and rye into one group, and wheat and oats into another, as regards this relation. With barley and rye, the largest, heaviest kernels are the richest in protein. With wheat and oats, the smallest, lightest kernels have the highest protein content.

Gwallig says further that with an increased protein content there is a decrease in nitrogen-free extract. The fat and ash do not stand in a definite relation to the kernel weight, but the small, light kernels have a higher percentage of crude fiber, which circumstance is accounted for by the larger surface possessed by the smaller kernels.

Snyder[b] has divided small kernels into two classes—those which are small because shrunken and those which are small although well filled. He finds that as between small kernels of the first class and large, well-filled kernels, the former contain a higher percentage of nitrogen, but as between the small, well-filled and the large, well-filled kernels, the latter contain the higher percentage of nitrogen. In testing this he used large and small kernels of the same variety in each case, and the wheats represented a large portion of the wheat-growing area of the United States. As regards the relation of large, perfect, and small, perfect kernels there were twenty-four out of twenty-seven cases in which the large kernels contained a greater percentage of nitrogen.

Johannsen and Weis,[c] in experiments with five varieties of wheat, find that as a general rule the percentage of nitrogen is increased with increasing grain weight, but that there are many exceptions to the rule.

Cobb[d] states that small wheat kernels contain a larger proportion of gluten than do large ones, but he does not submit any analyses to substantiate his statement.

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[a] Abstract in Centrlb. f. Agr. Chem., 24 (1895), p. 388, from Landw. Jahrbücher, 23 (1894), p. 835.

[b] Minnesota Experiment Station Bulletin 85.

[c] Abstract, Experiment Station Record, 12, p. 327, from Tidsskr. Landbr. Planteavl., 5 (1899), pp. 91–100.

[d] Agricultural Gazette of New South Wales, 5 (1894), No. 4, pp. 239–250.

Körnicke and Werner[a] quote the experiments of Reiset to show that shriveled kernels have a higher nitrogen content than plump ones. With different varieties of wheat he found the following:

Variety.	Kind.	Percentage of nitrogen in dry matter.
Spalding	Shriveled	2.48
Do	Plump	2.33
Victoria	Shriveled	2.44
Do	Plump	2.08
Albert	Shriveled	2.59
Do	Plump	2.35

Carleton[b] records the weight of 100 kernels and the percentage of "albuminoids" in sixty-one samples of wheat from various parts of the world. Dividing these into classes according to the weight of 100 kernels we have the following:

Weight of 100 kernels (grams).	Average weight of kernels (grams).	Percentage of albuminoids.	Number of samples.
2 to 3	2.66	14.58	6
3 to 4	3.67	12.31	25
over 4	4.57	11.62	30

Reviewing these experiments there would seem to be no doubt that shrunken kernels contain a higher percentage of nitrogen than do well-filled ones, but as between large and small kernels, both of which are well filled, there is not a great deal of information. Snyder's experiments are the only ones that cover this ground, but they are extensive and very uniform, and may be considered as deciding the question in favor of a higher nitrogen content for the large kernels, so far as small, plump kernels and large, plump kernels are concerned. But, as small and light kernels are usually not plump, taking the crop as a whole and dividing it equally into large and small or heavy and light kernels, the evidence would be in favor of the small or light kernels for high nitrogen content. As between wheats from different regions and of different varieties, those having small kernels are generally of higher nitrogen content.

INFLUENCE OF THE SPECIFIC GRAVITY OF THE SEED KERNEL UPON YIELD.

Sanborn[c] separated seed wheat with a sieve into large, medium, small, and shriveled kernels. The large seed was separated by means of a brine solution into two nearly equal parts. The seed thus separated was planted on separate plots. The experiment was continued three years. The heavy seed yielded 10.8 bushels and the light 16.3 bushels per acre. Unselected seed yielded 16.4 bushels per acre.

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[a] Handbuch des Getreidebaues, 1, pp. 520–521, Berlin, 1884.

[b] U. S. Department of Agriculture, Division of Vegetable Physiology and Pathology, Bulletin 24.

[c] Abstract, Experiment Station Record, 5, p. 58, from Utah Experiment Station Report, 1892, pp. 133–135.

Seed wheat of four varieties was separated by Church[a] by means of solutions of calcium chlorid having specific gravities of 1.247, 1.293, and 1.31. The seed was first treated with a solution of mercuric chlorid to remove adherent air. Each lot of seed was planted separately. From the results the following conclusions are drawn:

(1) The seed wheat of the greatest density produced the densest seed.

(2) The seed wheat of the greatest density yielded the largest amount of dressed grain.

(3) The seed of medium density generally gave the largest number of ears, but the ears were poorer than those from the densest seed.

(4) Seed of medium density generally produced the largest number of fruiting plants.

(5) The seed wheat that sank in water, but floated in a solution having the density 1.247, was of very low value, yielding on an average only 34.4 pounds of dressed grain for every 100 yielded by the densest seed.

Haberlandt,[b] as the result of experiments with several cereals, has shown that the comparative weight of kernels is transmitted to the grain resulting from this seed. This was the case with wheat, rye, barley, and oats. The results with wheat were as follows:

Number of pounds.	Weight of kernels.		
	Light.	Medium.	Heavy.
	Grams.	*Grams.*	*Grams.*
1,000 seed kernels	29.5	31.2	33.0
1,000 crop kernels	34.3	35.5	36.3

Wollny[c] objects to the results of the experiments by F. Haberlandt, Church, Trommer, Hellriegel, and Ph. Dietrich with various cereals, in which almost without exception the kernels of high specific gravity produced the best yields, because no distinction was made between absolute weight and specific gravity in the kernels. He claims that the value of the seed lies in the kernels of absolutely heavy weight rather than in the kernels of high specific gravity. He concludes that the specific gravity of the seed exerts no influence on the yield of the crop.

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[a] Science with Practice.

[b] Jahresb. Agr. Chem., 1866–67, p. 298.

[c] Abstract in Centrlb. f. Agr. Chem., 1887, p. 169, from Forschungen a. d. Gebiete Agrikulturphysik, 9 (1886), pp. 207–216.

In the light of the experiments that have been conducted with seed wheat of high and low specific gravities, it would appear that, in general, seed of very low specific gravity does not yield well, and it is evident that such seed must be deficient in mineral matter and is probably not normal in other respects. There would not appear, however, to be any marked difference in the productive capacity of kernels of medium specific gravity and kernels of great specific gravity.

RELATION OF SPECIFIC GRAVITY OF KERNEL TO NITROGEN CONTENT.

Marek[a] found that with an increase in the specific gravity of the kernel there was a decrease in nitrogen content.

Pagnoul,[b] in testing seventy varieties of wheat, found that the nitrogen content rose with the specific gravity, but not regularly, and that a definite relation could not be traced.

Wollny[c] took kernels of horny structure and kernels of mealy structure. He says it is generally recognized that the hard, horny kernels have a higher specific gravity, and that it is commonly attributed to their higher content of proteids. He contends that as starch has a higher specific gravity than protein the mealy kernels must really have a higher specific gravity than the horny ones.

Körnicke and Werner[d] state the specific gravities of the various chemical constituents of the wheat kernel as follows: Starch, 1.53; sugar, 1.60; cellulose, 1.53; fats, 0.91 to 0.96; gluten, 1.297; ash, 2.50; water, 1.00; air, 0.001293. They state also (p. 121) that the specific gravity of the kernel does not stand in any relation to the volume weight, for the factor which results from weighing a certain volume mass is influenced by the air spaces between the kernels, and these depend upon the form and size as well as the surface and accidental structure of the kernel. They also contend that there is no relation between the volume weight and the content of proteid material.

Schindler[e] shows that by tabulating a large number of varieties of wheat from different parts of the world, and representing different varieties, there is no relation between the weight of 1,000 kernels and the volume weight of 100 c. c. By separating these into varieties, even when grown in different localities, kernels of the same variety did show a definite and constant relation. The volume weight increased with an increase in the weight of 1,000 kernels.

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[a] Abstract in Centrlb. f. Agr. Chem., 1876, p. 46, from Landw. Zeitung f. Westfalen u. Lippe, 1875, p. 362.

[b] Abstract in Centrlb. f. Agr. Chem., 1888, p. 767, from Ann. Agron., 14, pp. 262–272.

[c] Abstract in Centrlb. f. Agr. Chem., 1887, p. 169, from Forschungen a. d. Gebiete Agrikulturphysik, 9 (1886), pp. 207–216.

[d] Handbuch des Getreidebaues, 2, p. 120, Berlin, 1884.

[e] Jour. Landw., 45 (1897), p. 61.

There has long been a desire manifested by workers in this field to establish some definite relation between the specific gravity of the wheat kernel and its composition, or at least its nitrogen content. Very contradictory results have been obtained by several experimenters, and little progress has been made.

It is true that the various chemical constituents that go to compose the wheat kernel have different specific gravities, and as those of the carbohydrates are all less than those of the proteids it might be argued that a wheat having a large proportion of proteid material would have a low specific gravity. However, the specific gravity of the ash is so much greater than that of any other constituent and the ash in wheats from different soils and climates varies so much that these factors completely prevent the establishment of a definite relation. The size and number of the vacuoles also influence the specific gravity.

In general, it may be said that as between kernels of the same variety grown in the same season and upon the same soil, the specific gravity is inversely proportional to the nitrogen content.

CONDITIONS AFFECTING THE PRODUCTION OF NITROGEN IN THE GRAIN.

So far as the writer has been able to ascertain there is no literature bearing directly upon the conditions affecting the production of nitrogen in the grain of wheat.

Regarding high nitrogen in the wheat crop as arising merely from failure on the part of the kernel to develop fully, it would seem that a high percentage of nitrogen would inevitably be accompanied by a small production of nitrogen per acre. This, however, does not always appear to be the case.

Taking, for instance, the yields of wheat obtained by Lawes and Gilbert[a] for a period of twenty years, which they divide into two periods of good and of poor crops, each covering ten years, we have the following figures:

Seasons.	Average yield of grain per acre (pounds).	Weight per bushel (pounds).	Yield of nitrogen per acre (pounds).
Good crop seasons	1,833	60.2	28.0
Poor crop seasons	1,740	57.1	29.8

It will be noticed that the largest production of nitrogen per acre was in those years in which the weight per bushel and the yield per acre were least.

Of course this is not always the case, but that it should occur at all is an indication that the conditions that make for high nitrogen content in the grain also conduce to a large accumulation of nitrogen by the crop, or perhaps it would be more accurate to say that the conditions which favor a large accumulation of nitrogen by the crop often result in giving it a high nitrogen content.

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[a] On the Composition of the Ash of Wheat Grain and Wheat Straw, London, 1884.

Reference has already been made to the observations of Dehérain and Dupont[a] on the wheat crops of 1888 and 1889 at Grignon. The figures for the yields of grain, the percentages of starch and gluten, and the production per acre of these constituents for the two years are as follows:

Year.	Yield of grain per hectare (kilos).	Percentage of—		Gluten per hectare (kilos).	Starch per hectare (kilos).
		Gluten.	Starch.		
1888	3,445	12.6	77.2	434	2,659
1889	2,922	15.3	61.9	447	1,808

From this it will be seen that for the year in which the yield of grain was less per acre the production of gluten per acre was greater. Apparently the conditions were favorable for a large accumulation of nitrogen by the plant in 1889, but were unfavorable to the production of starch. If the latter had not been the case, the crop of 1889 would have been larger than the crop of 1888.

A number of instances of this kind have occurred among the wheat crops at the Nebraska Experiment Station. In fact, it may be said that, in general, large yields of grain have there been accompanied by a low percentage of nitrogen per acre as compared with the same properties in small yields of grain. The following table will show this:

Production of nitrogen per acre in wheat raised at the Nebraska Experiment Station.

Variety.	Year.	Yield of grain per acre (pounds).	Percentage of proteid nitrogen.	Proteid nitrogen per acre (pounds).	Date of ripening.
Turkish Red	1900	1,980	3.02	52.73	June 27
Do	1901	2,370	2.00	43.04	June 24
Do	1902	1,800	2.86	51.48	June 23
Do	1903	1,864	2.40	44.74	July 9
Yaroslav	1900	1,320	3.01	34.58	July 2
Do	1901	1,794	2.18	36.08	July 1
Do	1903	[a]962	2.54	24.43	July 14
Weissenburg	1902	1,605	3.16	46.32	June 24
Do	1903	1,891	2.10	39.71	July 10
Pester Boden	1902	1,475	2.92	43.10	June 24
Do	1903	1,830	2.16	39.53	July 10
Average		1,717		41.43	

[a] Yield decreased by lodging of grain.

A word in regard to the character of the seasons that produced these crops may help to an understanding of their differences.

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[a] Ann. Agron., 28 (1902), p. 522.

The season of 1900 was rather dry and hot from the time growth started in the spring until harvest. There was no time when there was an abundant supply of moisture, but occasional rains wet the soil for a few days at a time. The temperatures during the day were high and the air was dry. In 1901 the spring was quite moist and cool until June, when it became extremely hot and dry. A few days before harvest the temperatures ranged above 100° F. daily, with no rainfall. The season of 1902 was the direct opposite of that of 1901, except that the change came earlier. It was extremely dry and hot until the middle of May, when abundant rains came, and the temperatures were considerably below normal until harvest. The season of 1903 was wet and cool throughout.

In general, it may be said that in those seasons, like 1900 and 1902, in which the temperatures were high and moisture scarce during all or the early part of the growing season, the grain had a high percentage of nitrogen, and there was a large production of nitrogen per acre. In years of low temperatures and abundant moisture, as in 1903, or even when such conditions obtained late in the season, as in 1901, there were a low percentage of nitrogen in the grain and a small production of nitrogen per acre.

High temperatures and scant moisture during early growth would, therefore, seem to favor the accumulation of nitrogen by the wheat plant.

It may also be noted that these are the conditions favorable to the process of nitrification and to the accumulation of nitrates near the surface of the soil.

Comparing the wheat crops grown at Rothamsted for a period of twenty years, the yields and nitrogen production of which have just been stated, with the averages for the Nebraska-grown wheats contained in the last table, it will be seen that the yields of grain were larger at Rothamsted, but that the production of nitrogen per acre was considerably greater in Nebraska.[a]

Station.	Yield (in pounds) per acre of—	
	Grain.	Nitrogen.
Rothamsted station	1,786	28.9
Nebraska station	1,717	41.4

The maximum production of nitrogen per acre at Rothamsted during the twenty years was 38.1 pounds, while at Nebraska it was 52.7 pounds.

There can be little doubt as to whether this difference was due in greater measure to soil fertility or to climate. Nowhere is better tillage given or are crops more scientifically provided with food than at Rothamsted. It is true that of the ten plots of land on which these wheats were raised one received no manure and three were not sufficiently manured. In order to make the comparison more favorable to the English environment, the five plots completely manured and producing the largest yields may be taken. The yield of nitrogen per acre was 36.4 pounds for the years 1852–1861 and 34.6 pounds for 1862–1871. Even with the best manuring the yields of nitrogen fall very much short of those in Nebraska.

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[a] The yield of nitrogen at Rothamsted is calculated from total organic nitrogen, while at the Nebraska Station it is from proteid nitrogen.

In Nebraska no commercial fertilizers had ever been used on the land on which the wheats were grown, but farm manure had been applied. The soil was a heavy one, well adapted to wheat growing, and had been well tilled. It had been well manured for corn in a rotation of corn, oats, and wheat. The varieties, with the exception of Turkish Red, had just been introduced from Europe and had not fully adapted themselves to the new environment. The average nitrogen production for the only acclimated variety, Turkish Red, was 48 pounds per acre. It would seem, therefore, that a climate affording high temperatures, dry air, and a moderately dry soil is favorable to the accumulation of a large amount of nitrogen by the wheat plant, provided there is a large supply of nitrogen in the soil.

The heat and scant soil moisture are doubtless instrumental in making available the nitrogen of the humus, and the bright sunshine and dry, hot air stimulate growth and increase transpiration.

It has just been said that hot, dry weather in the early growing season contributes to a large nitrogen accumulation by the wheat plant. The same conditions cut short the growing period of the plant and prevent the large accumulation of starch that takes place in the kernel of wheat raised in a cool or moist region. It thus happens that such wheats are high in nitrogen and low in starch.

The properties of the wheat kernel characteristic of a continental climate and rich soil are probably due to rapid nitrification and highly stimulated growth causing a large accumulation of nitrogen by the crop, and to incomplete maturation, caused either by heat, or frost, or lack of moisture, resulting in high nitrogen.

It would be interesting to know what relation the production of nitrogen per acre bears to the production of mineral matter, but the necessary figures are not at hand.

The wheat kernel produced in a continental climate is not usually plump as compared with the kernel produced in an insular or coastal one. The yield of grain per acre is also usually less. That this is due to incomplete maturation is shown by the fact that winter varieties of wheat that make their growth early in the season always yield better than spring varieties. The latter, on the other hand, have a higher percentage of nitrogen, but usually not so large a nitrogen production. Their disadvantage lies in the fact that their roots are not sufficiently developed to absorb a large quantity of nitrogenous matter at the time most favorable for its accumulation. As a maximum nitrogen accumulation is the chief desideratum, spring wheats are not desirable where winter ones can be grown.

This does not mean that a variety of wheat which has been grown, for instance, in England will show all the qualities of an inland wheat when first grown in Kansas or Nebraska. Such a wheat will undergo modifications that will give it some of these qualities, such, for instance, as less well-filled kernels, and less weight per bushel. On the other hand, the Turkish Red wheat, when raised in a cool, moist climate, becomes later maturing, and the kernel becomes plumper, more starchy, and softer. It is between varieties adapted each to its peculiar climate, and raised there for years, that these distinctions are most marked, but the fact that a modification of any variety begins at once when transferred from one climate to another shows that such qualities as those mentioned are influenced by the climate.

It must be quite apparent, although it has not often been remarked, that the ordinary selection of seed wheat to increase the yield has resulted in producing a grain of lower nitrogen content.

This has been noticed by Girard and Lindet[a] and by Biffen,[b] and incidentally by Balland,[c] who, in commenting on the decrease in the nitrogen content of wheat in northern France and the increased yields, attributes the former to a deficiency of nitrogen in the fertilizers used, and states that the gluten in the wheat of that region in 1848 ranged from 10.23 to 13.02 per cent, while fifty years later it ranged from 8.96 to 10.62 per cent. In the same time the average yield increased from 14 to 17.5 hectoliters per hectare. In the light of the results of experiments to ascertain the effect of nitrogenous fertilizers upon the composition of wheat, it can not be supposed that this decrease in nitrogen content can be due primarily to lack of nitrogen. It would seem more likely that the increased yield was largely due to the deposition of starch in the grain, and that consequently the percentage of gluten was smaller.

Has the improvement in the yield of wheat been accompanied by a greater yield of nitrogen per acre? It is evident that the increase in the grain and that in the nitrogen are not proportional, but it is desirable to know whether there has been any increase in nitrogen per acre. Returning to the figures given by Balland it will be seen that the wheat of 1848 produced on an average 163 kilos per hectare, while that of fifty years later produced 171 kilos, an increase of about 5 per cent in gluten per hectare, with an increase of 25 per cent in yield. These figures can not, of course, be taken as strictly accurate, as they are based merely on what M. Balland refers to as the range of nitrogen content.

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[a] Le Froment et sa Monture, Paris, 1903.

[b] Nature (London), 69 (1903), No. 1778, pp. 92, 93.

[c] Abstract in Centrlb. f. Agr. Chem., 1897, p. 785, from Compt. Rend., 124 (1897), p. 158.

Some data on this subject are available in the published records of wheat improvement at the Minnesota Experiment Station.[a] Yields and gluten content of improved varieties and of the original variety from which the improved strains have been developed by selection are given. The figures cover the same seasons for all varieties, and the averages of six trials are reported for each, as follows:

Variety.	Yield per acre (bushels).	Percentage of dry gluten.	Gluten per acre (pounds).	Nitrogen per acre (pounds).
Minnesota No. 149, produced from Power's Fife	25.6	13.5	207.4	36.4
Power's Fife, unmodified by selection	23.6	14.0	198.2	34.8
Minnesota No. 169, produced from Hayne's Blue Stem	28.5	12.5	213.7	37.5
Hayne's Blue Stem, unmodified by selection	24.6	13.4	198.8	34.7

In each case the new variety yielded more grain per acre, possessed a lower gluten content, and produced more nitrogen per acre in the grain. It should be explained that determinations of gluten and baking tests were made of strains of wheat produced by the selection of individual plants, and that the quantity and quality of the gluten in these strains were considered in deciding which strain was to be perpetuated. For that reason the gluten content of the improved wheat is doubtless greater than it would have been if no attention had been paid to those qualities. Incidentally it may be stated that the quality of the gluten in these new varieties of wheat originated by Professor Hays is much better than that in the original varieties. The difference between selection for gluten carried on in this way and selection for gluten applied to the individual plant is that the latter must increase many times the opportunity for developing a strain of desirable gluten content.

Returning to the nitrogen production per acre, it is apparent that it is slightly greater in the improved wheats, or at least is not less than in the original varieties. This is encouraging, as it indicates the possibility of increasing the production of gluten per acre.

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[a] Minnesota Experiment Station Bulletin 63.

Gluten is the valuable constituent of wheat. The wheat growing of the future may be looked upon as a gluten-producing industry. The problem is to secure the highest possible quantity and quality of gluten per acre. If this can be done by sacrificing starch production, it will be economical. Starch can be more cheaply produced in other crops and, if necessary, added to the flour of wheat.

It may be argued that this is not to the interest of the farmer. But it is clearly to the interest of mankind and any step toward its accomplishment must in the end redound to the advantage of the farmer.

PART II.

EXPERIMENTAL.

SOME PROPERTIES OF THE WHEAT KERNEL.

If a number of wheat kernels of the same variety and raised under similar conditions are separated into approximately equal parts with regard to their specific gravity, the kernels of low specific gravity will be found to contain a higher percentage of both total and proteid nitrogen than the kernels having a high specific gravity.

A number of samples of wheat grown in different years and representing different varieties were separated into approximately equal parts by throwing the kernels into a solution of calcium chlorid having such a density that about half the kernels would float and the other half sink. The specific gravity of the solution in which each sample was separated is given in Table 1 and the signs < and > are used to represent "less than" and "greater than," respectively. Thus "<1.29" means that the kernels have a specific gravity of less than 1.29, while ">1.29" indicates that the kernels have a specific gravity greater than 1.29.

Table 1.—*Analyses of kernels of high and of low specific gravity.*

Serial number.	Specific gravity.	Percentage of—			Name of variety and year of growth.
		Total nitrogen.	Proteid nitrogen.[a]	Nonproteid nitrogen.	
1	<1.290	3.51	2.49	1.02	Hickman, grown in 1895.
2	>1.290	3.27	2.39	.88	
30	<1.286	2.51	1.88	.63	Turkish Red, grown in 1897.
31	>1.286	2.51	1.94	.57	
38	<1.250	2.80	2.26	.54	Spring wheat, Marvel, grown in 1897.
39	>1.250	2.78	2.15	.63	
40	<1.265	2.95	2.13	.82	Spring wheat, Velvet Chaff grown in 1897.
41	>1.265	2.66	2.01	.65	
59	<1.264	3.30	2.41	.89	Turkish Red, grown in 1898.
60	>1.264	3.06	2.29	.77	

[a] Proteid nitrogen in this paper = nitrogen by Stutzer's method. Proteids = proteid nitrogen × 5.7.

With the exception of serial Nos. 30 and 31 the kernels of low specific gravity have in each case a higher percentage of both total and proteid nitrogen than have the kernels of high specific gravity. It will also be noticed that the percentage of nonproteid nitrogen is greater in the kernels of low specific gravity.

Samples of wheat were also divided into light and heavy portions by means of a machine which operates by directing upward a current of air, the velocity of which can be regulated. Into this current the grain is directed. The result is that the heavy kernels and the large kernels fall, and the light kernels and small kernels are driven out. The separation thus accomplished is somewhat different from that effected by a solution, the difference being that the latter separates the kernels entirely according to their specific gravities while with the air blast a large kernel of a certain specific gravity might descend with the heavy kernels, when if it were smaller, although of the same specific gravity, it would be blown out.

The number of light kernels that descend on account of their large size is relatively small, owing to the fact that large kernels are, as a rule, of higher specific gravity than small ones. The following test was made to determine the relation between the size of wheat kernels and their specific gravity. An average lot of wheat was nearly equally divided by means of two sieves into three portions representing medium, small, and large kernels. Each of these portions was then thrown upon solutions of the same specific gravity, and the proportion by weight that floated, or light seed, and the proportion that sank, or heavy seed, were determined.

TABLE 2.—*Proportion of light and of heavy seed.*

Kind of seed.	Heavy seed (grams).	Light seed (grams).	Ratio.	
			Heavy.	Light.
Small	8.72	11.28	1	1.29
Medium	9.62	10.78	1	1.12
Large	11.96	8.04	1	.67

The weight of light kernels among the small was nearly twice that of light kernels among the large seeds.

Analyses of samples of wheat separated by this machine into light and heavy kernels gave about the same results as the samples separated by solutions of certain specific gravities.

TABLE 3.—*Analyses of large, heavy kernels and of small, light kernels.*

Serial number.	Relative weight.	Percentage of—			Name of variety and year of growth.
		Total nitrogen.	Proteid nitrogen.	Nonproteid nitrogen.	
9	Light	2.99	2.21	0.78	Spring wheat, Marvel, grown in 1896.
10	Heavy	2.76	2.04	.72	
57	Light	2.77	2.11	.66	Currell, grown in 1898.
58	Heavy	2.70	2.04	.66	
65	Light	2.91	2.29	.62	Spring wheat, grown in 1898.
66	Heavy	2.65	2.04	.61	
80	Light	2.45	2.00	.45	Big Frame, grown in 1899.
81	Heavy	2.19	1.96	.23	
383	Light	3.12	3.10	.02	Turkish Red, grown in 1900.
384	Heavy	3.02	2.93	.09	
385	Light	3.13	2.82	.31	Big Frame, grown in 1900.
386	Heavy	2.95	2.65	.30	
602	Light	3.30	3.06	.24	Big Frame, grown in 1901.
603	Heavy	2.46	2.24	.22	
613	Light	2.35	2.13	.22	Turkish Red, grown in 1901.
612	Heavy	2.11	1.94	.17	

It thus becomes very apparent that the percentage of nitrogen is relatively greater in the light wheat selected in the manner described.

It is well known that immature wheat is of lighter weight than mature wheat and that it contains a greater percentage of nonproteid nitrogen. In a field of wheat there are always certain plants that mature early, others that mature late, and some that never reach a normal state of maturity. The last condition is very likely to occur in a region of limited rainfall and intense summer heat. The conditions most favorable for the filling out of the grain are shown to be an abundance of soil moisture and a fair degree of warmth. The more nearly the conditions are the reverse of this the more shriveled the kernel and the lighter the weight. In the same variety and in the same field there are kernels that are small and shriveled because of immaturity, disease, or lack of nutriment. All of these classes would appear among the "light" kernels separated in this way.

In order to approach the question from another standpoint, a number of spikes of wheat of the Turkish Red variety were selected in the field, care being taken that all were fully ripe, and that they were composed of healthy, well-formed kernels. These spikes were sampled by removing one row of spikelets from each spike and the kernels so removed were tested for moisture, proteid nitrogen, specific gravity, and weight of kernel, and from the last two the relative volume was calculated. It will be shown later that a sample taken in this way permits of an accurate estimation of the average composition of the kernels on the spike.

The number of grams of proteid nitrogen in the row of spikelets on each spike was calculated from the data mentioned, and the average weight of the kernels on the row of spikelets was determined from their total weight and number, thus permitting of the estimation of the number of grams of proteid nitrogen in the average kernel on each spike.

In Table 4 the spikes having a proteid nitrogen content of from 2 to 2.5 per cent are arranged in one group, and on the same line with each spike are placed the number of kernels on one row of spikelets, weight of these kernels, weight of average kernel, relative volume of average kernel, specific gravity of kernel, grams of proteid nitrogen in one row of spikelets, and grams of proteid nitrogen in average kernel. Spikes having a proteid nitrogen content of from 2.5 to 3 per cent are similarly arranged, and so with all spikes up to 4 per cent. The average for each group is shown in the table.

There are, in all, 257 spikes, of which 18 have from 2 to 2.5 per cent proteid nitrogen, 82 from 2.5 to 3 per cent, 107 from 3 to 3.5 per cent, and 49 from 3.5 to 4 per cent.

TABLE 4.—*Analyses of spikes of wheat, arranged according to nitrogen content of kernels. Crop of 1902.*

2 TO 2.5 PER CENT PROTEID NITROGEN.

Record number.	Number of kernels on row of spikelets.	Weight (in grams) of—		Volume of average kernel.	Specific gravity of kernels.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—	
		Kernels.	Average kernel.				Kernels.	Average kernel.
183........	17	0.4772	0.0280	....	....	2.06	0.00983	0.000577
188........	16	.4425	.0276	....	....	2.37	.01049	.000654
193........	14	.3724	.0266	....	....	2.41	.00897	.000642
205........	15	.4824	.0321	0.0241	1.3323	2.41	.01548	.000774
291........	18	.5221	.0290	.0209	1.3850	2.23	.01616	.000647
304........	21	.5336	.0254	.0189	1.3424	2.24	.01195	.000569
318........	22	.6708	.0304	.0220	1.3853	2.02	.01354	.000614
347........	15	.4549	.0303	.0216	1.4031	2.44	.01110	.000739
357........	15	.4063	.0270	.0192	1.4074	2.36	.00959	.000637
358........	21	.6689	.0318	.0235	1.3544	2.33	.01559	.000742
380........	14	.4336	.0309	.0225	1.3735	2.35	.01019	.000726
396........	19	.4787	.0251	.0183	1.3680	2.28	.01091	.000572
402........	17	.4594	.0258	.0188	1.3718	2.33	.01070	.000601
406........	21	.5878	.0279	.0200	1.3915	2.44	.01434	.000681
415........	13	.2771	.0213	....	....	2.44	.00676	.000520
440........	17	.4566	.0268	....	....	2.36	.01078	.000632
444........	16	.4110	.0256	....	....	2.38	.00978	.000609
445........	16	.4318	.0269	....	....	2.37	.01023	.000638
Average...	17	.4759	.0266	.0209	1.374	2.323	.01141	.000643

2.5 TO 3 PER CENT PROTEID NITROGEN.

181........	19	0.4482	0.0235	....	....	2.66	0.01192	0.000625
182........	17	.4299	.0252	....	....	2.76	.01187	.000696
185........	19	.5041	.0265	....	....	2.71	.01366	.000718
187........	15	.3945	.0263	....	....	2.99	.01180	.000786
189........	18	.4871	.0270	....	....	2.64	.01286	.000713
196........	17	.4995	.0293	....	....	2.71	.01354	.000794
197........	20	.5683	.0284	....	....	2.85	.01620	.000809
199........	17	.4589	.0269	....	....	2.99	.01372	.000804
207........	15	.4584	.0305	0.0230	1.3248	2.73	.01709	.000833
210........	14	.3955	.0282	.0288	1.2363	2.95	.01167	.000832
211........	17	.5211	.0306	.0228	1.3416	2.90	.01511	.000887
212........	15	.4298	.0286	.0211	1.3537	2.97	.01277	.000849
217........	18	.6299	.0349	.0259	1.3461	2.86	.01802	.000998
218........	18	.5130	.0285	.0214	1.3303	2.58	.01324	.000735
219........	19	.3862	.0203	.0157	1.2950	2.71	.01047	.000550
222........	19	.4611	.0242	.0182	1.3331	2.93	.01351	.000709
227........	19	.5581	.0293	.0214	1.3704	2.71	.01624	.000794
229........	17	.4849	.0285	.0206	1.3856	2.96	.01387	.000844
230........	15	.4867	.0324	.0234	1.3815	2.54	.01236	.000823
238........	17	.5166	.0303	.0220	1.3794	2.70	.01395	.000818
239........	17	.3910	.0230	.01649	1.3941	2.60	.01017	.000598
241........	18	.4230	.0235	.0178	1.3196	2.76	.01168	.000649
242........	18	.4562	.0253	.0184	1.3753	2.96	.01350	.000749
252........	19	.4898	.02578	.0186	1.3875	2.55	.01249	.000655
277........	14	.3792	.0270	.0203	1.3286	2.86	.01085	.000772
288........	17	.4956	.0291	.0217	1.3428	2.82	.01398	.000821
289........	19	.5042	.0265	.0187	1.4155	2.53	.01276	.000670
293........	17	.4858	.0285	.0206	1.3835	2.64	.01283	.000752
294........	19	.4173	.0219	.0159	1.3813	2.56	.01068	.000561
302........	22	.5569	.0253	.0190	1.3312	2.68	.01437	.000678
306........	19	.4922	.0258	.0185	1.3996	2.51	.01235	.000650
308........	15	.4951	.0330	.0237	1.392	2.85	.01411	.000941
315........	16	.4994	.0312	.0224	1.3916	2.75	.01373	.000858
319........	17	.4644	.0273	.0203	1.3447	2.86	.01328	.000781
320........	18	.5668	.0314	.0229	1.3710	2.98	.01689	.000938
322........	16	.5107	.0219	.0236	1.352	2.55	.01302	.000813
329........	12	.3903	.0325	.0234	1.3911	2.88	.01241	.000936
330........	17	.3431	.0201	.0161	1.2498	2.62	.00899	.000527
332........	16	.4847	.0302	.0218	1.3879	2.58	.01251	.000779
334........	18	.5399	.0299	.0215	1.3922	2.62	.01415	.000783
335........	18	.6474	.0359	.0258	1.3928	2.82	.01826	.001012
337........	15	.4497	.0299	.0215	1.3877	2.89	.01345	.000864
340........	20	.4155	.0207	.0153	1.3550	2.74	.01138	.000567
341........	15	.5058	.0337	.0243	1.3890	2.97	.01502	.001001
342........	14	.4486	.0320	.0228	1.4037	2.60	.01166	.000832
343........	13	.4112	.0316	.0224	1.4107	2.50	.01028	.000791
344........	16	.4004	.0250	.0184	1.3611	2.93	.01173	.000733
345........	18	.5122	.0301	.0216	1.3919	2.56	.01388	.000771
346........	19	.6393	.0336	.0242	1.3913	2.55	.01630	.000857
348........	18	.6328	.0351	.0262	1.3415	2.88	.01822	.001010

TABLE 4.—*Analyses of spikes of wheat, arranged according to nitrogen content of kernels. Crop of 1902*—Continued.

2.5 TO 3 PER CENT PROTEID NITROGEN—Continued.

Record number.	Number of kernels on row of spikelets.	Weight (in grams) of— Kernels.	Weight (in grams) of— Average kernel.	Volume of average kernel.	Specific gravity of kernels.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in— Kernels.	Proteid nitrogen (gram) in— Average kernel.
349	17	0.4573	0.0269	0.0195	1.3822	2.66	0.01216	0.000716
350	16	.4437	.0277	.0199	1.3891	2.64	.01171	.000731
354	21	.6386	.0304	.0217	1.4002	2.73	.01743	.000830
355	16	.5008	.0313	.0223	1.4022	2.84	.01422	.000889
356	19	.5304	.0279	.0200	1.390	2.91	.01543	.000812
359	15	.3882	.0259	.0186	1.3915	2.97	.01153	.000769
360	24	.6375	.0265	.0191	1.3840	2.89	.01842	.000766
361	14	.3297	.0235	.0170	1.3819	2.94	.00969	.000691
364	18	.4724	.0262	.0191	1.3729	2.92	.01379	.000765
371	18	.5695	.0316	.0227	1.3906	2.99	.01703	.000945
373	18	.5861	.0325	.0235	1.3838	2.87	.01682	.000933
376	12	.2677	.0223	.0162	1.3747	2.60	.00696	.000580
378	14	.4099	.0292	.0212	1.3761	2.75	.01127	.000803
383	12	.3416	.0284	.0206	1.3771	2.96	.01011	.000841
386	16	.4921	.0307	.0223	1.3741	2.52	.01240	.000774
387	19	.5177	.0272	.0198	1.3758	2.73	.01413	.000743
389	21	.5830	.0277	.0204	1.3569	2.96	.01726	.000820
392	16	.3547	.0221	.0171	1.2947	2.94	.01043	.000650
393	15	.3491	.0232	.0165	1.4070	2.70	.00943	.000626
394	16	.3897	.0243	.0180	1.3508	2.77	.01079	.000673
395	17	.4805	.0282	.0206	1.3693	2.98	.01432	.000840
419	14	.3448	.0246	....	....	2.86	.00986	.000704
421	15	.3097	.0206	....	....	2.53	.00784	.000521
424	18	.4991	.0277	....	....	2.62	.01308	.000726
428	17	.4635	.0272	....	....	2.60	.01205	.000707
430	18	.5714	.0317	....	....	2.82	.01611	.000894
434	16	.4624	.0289	....	....	2.86	.01322	.000827
436	22	.6138	.0279	....	....	2.88	.01768	.000834
438	23	.6997	.0304	....	....	2.67	.01868	.000812
439	18	.5600	.0311	....	....	2.98	.01669	.000927
441	19	.5327	.0280	....	....	2.93	.01561	.000820
443	13	.4131	.0317	....	....	2.51	.01037	.000796
Average	17.07	.4791	.0279	.0207	1.3680	2.76	.01332	.000776

3 TO 3.5 PER CENT PROTEID NITROGEN.

173	20	0.5913	0.0295	....	....	3.08	0.01821	0.000909
175	21	.5773	.0274	....	....	3.46	.01997	.000948
176	20	.5804	.0290	....	....	3.10	.01799	.000899
190	18	.4673	.0259	....	....	3.25	.01519	.000842
191	17	.4279	.0251	....	....	3.25	.01091	.000816
192	17	.4126	.0242	....	....	3.12	.01287	.000755
194	13	.3218	.0247	....	....	3.43	.01104	.000847
195	19	.4924	.0259	....	....	3.33	.01640	.000862
198	18	.4683	.0260	....	....	3.18	.01489	.000827
200	18	.5764	.0320	....	....	3.24	.01868	.001040
202	14	.3824	.0273	0.0200	1.3615	3.13	.01197	.000854
203	16	.5251	.0328	.0241	1.3614	3.07	.01612	.001007
206	17	.3392	.0199	.0157	1.2709	3.44	.01166	.000685
208	19	.4939	.0259	.0192	1.3494	3.21	.01585	.000831
213	15	.4116	.0274	.0204	1.3415	3.31	.01362	.000907
214	16	.4371	.0273	.0208	1.3082	3.09	.01351	.000844
216	15	.3122	.0208	.0165	1.2588	3.33	.01040	.000693
220	17	.5040	.0296	.0222	1.3350	3.20	.01613	.000947
223	17	.4795	.0282	.0204	1.3970	3.31	.01587	.000933
226	21	.5380	.0256	.0170	1.4951	3.11	.01673	.000796
228	14	.4143	.0295	.0211	1.3945	3.40	.01409	.001003
231	18	.5888	.0327	.0242	1.3514	3.11	.01831	.001017
232	13	.3825	.0294	.0221	1.3280	3.11	.01190	.000914
233	17	.5331	.0313	.0231	1.3558	3.32	.01663	.001039
234	16	.5201	.0325	.0243	1.3363	3.23	.01680	.001050
236	25	.7451	.0298	.0220	1.3504	3.19	.02377	.000951
243	24	.6349	.0264	.0196	1.3487	3.47	.02203	.000916
244	19	.5839	.0307	.0214	1.4305	3.30	.01927	.001013
249	16	.4415	.0275	.0199	1.3850	3.21	.01417	.000883
250	15	.4514	.0300	.0213	1.4100	3.12	.01408	.000936
251	22	.6190	.0281	.0203	1.3823	3.46	.02142	.000972
255	18	.5948	.0330	.0233	1.4146	3.03	.01802	.001000
256	21	.5277	.0251	.0184	1.3629	3.31	.01747	.000832
258	17	.4703	.0276	.0211	1.3065	3.38	.01590	.000933

TABLE 4.—*Analyses of spikes of wheat, arranged according to nitrogen content of kernels. Crop of 1902*—Continued.

3 TO 3.5 PER CENT PROTEID NITROGEN—Continued.

Record number.	Number of kernels on row of spikelets.	Weight (in grams) of—		Volume of average kernel.	Specific gravity of kernels.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—	
		Kernels.	Average kernel.				Kernels.	Average kernel.
262	18	0.4604	0.0255	0.0193	1.3216	3.20	0.01473	0.000816
263	18	.5040	.0280	.0197	1.4206	3.24	.01633	.000907
264	18	.4138	.0229	.0169	1.3544	3.37	.01395	.000772
265	18	.4429	.0246	.0189	1.3005	3.30	.01462	.000812
266	19	.5010	.0263	.0187	1.4090	3.11	.01558	.000818
269	17	.4531	.0266	.0209	1.2748	3.21	.01454	.000854
270	20	.5183	.0259	.0191	1.3541	3.37	.01747	.000873
271	14	.3275	.0233	.0177	1.3143	3.39	.01110	.000790
272	15	.3858	.0257	.0190	1.3564	3.14	.01212	.000807
273	18	.4559	.0253	.0178	1.4228	3.39	.01546	.000858
275	18	.4862	.0270	.0197	1.3711	3.33	.01619	.000899
276	15	.3973	.0264	.0191	1.3815	3.15	.01251	.000832
278	15	.4715	.0314	.0226	1.3903	3.12	.01471	.000980
281	21	.6938	.0330	.0241	1.3693	3.26	.02262	.001076
282	18	.4973	.0276	.0200	1.3795	3.02	.01502	.000834
295	19	.5205	.0273	.0201	1.3608	3.06	.01593	.000835
300	19	.4994	.0262	.0188	1.3945	3.07	.01533	.000894
301	16	.5492	.0343	.0249	1.3787	3.09	.01697	.001060
305	13	.3452	.0265	.0197	1.3432	3.07	.01060	.000814
307	20	.4122	.0206	.0140	1.4727	3.19	.01315	.000657
310	18	.4867	.0270	.0198	1.3681	3.16	.01538	.000853
312	15	.4324	.0288	.0210	1.3718	3.49	.01509	.001005
314	15	.4122	.0274	.0201	1.3657	3.16	.01303	.000866
316	17	.4157	.0244	.0178	1.3733	3.36	.01397	.000820
317	17	.4412	.0259	.0193	1.3424	3.43	.01513	.000888
321	18	.5484	.0304	.0207	1.4660	3.43	.01881	.001043
323	17	.4075	.0239	.0177	1.3487	3.43	.01398	.000820
324	17	.4230	.0248	.0180	1.3740	3.19	.01349	.000791
325	17	.5110	.0300	.0220	1.3658	3.46	.01768	.001038
327	16	.4039	.0252	.0191	1.3225	3.45	.01393	.000869
333	16	.4610	.0288	.0206	1.3956	3.26	.01503	.000939
336	13	.3637	.0279	.0198	1.4102	3.36	.01222	.000937
339	16	.3803	.0237	.0171	1.3828	3.33	.01266	.000789
351	15	.3843	.0256	.0186	1.3812	3.32	.01276	.000851
352	15	.4497	.0299	.0217	1.3829	3.05	.01372	.000914
353	16	.4726	.0295	.0211	1.3988	3.11	.01470	.000917
362	19	.5258	.0276	.0201	1.3701	3.03	.01593	.000836
366	17	.4214	.0247	.0185	1.3350	3.17	.01336	.000783
367	20	.5351	.0267	.0197	1.3555	3.37	.01803	.000900
368	19	.3877	.0204	.0151	1.3497	3.06	.01186	.000624
369	19	.5560	.0292	.0214	1.3621	3.34	.01857	.000975
370	17	.4200	.0247	.0180	1.3735	3.09	.01298	.000763
372	17	.4811	.0283	.0206	1.3714	3.31	.01593	.000937
374	17	.5249	.0308	.0218	1.4142	3.15	.01653	.000970
375	18	.5147	.0285	.0203	1.4018	3.41	.01755	.000975
377	14	.3173	.0226	.0174	1.3013	3.47	.01101	.000784
379	18	.5271	.0292	.0213	1.3703	3.09	.01629	.000902
381	13	.3506	.0269	.0199	1.3544	3.45	.01210	.000928
382	19	.5057	.0266	.0194	1.3728	3.23	.01633	.000859
388	19	.5799	.0305	.0221	1.3773	3.05	.01769	.000930
390	19	.4764	.0250	.0181	1.3806	3.22	.01534	.000805
391	18	.4474	.0248	.0182	1.3628	3.26	.01459	.000808
399	12	.3058	.0254	.0188	1.3510	3.10	.00948	.000787
400	20	.5720	.0286	.0206	1.3837	3.35	.01916	.000958
401	16	.3996	.0249	.0183	1.3575	3.37	.01347	.000839
403	17	.5000	.0294	.0211	1.3927	3.04	.01520	.000894
404	18	.4286	.0238	.0180	1.3221	3.30	.01414	.000785
410	20	.5368	.0268			3.27	.01755	.000780
411	14	.3479	.0248			3.15	.01096	.000781
414	19	.5044	.0265			3.14	.01584	.000832
416	15	.4269	.0284			3.24	.01383	.000920
418	21	.4995	.0237			3.05	.01523	.000723
423	18	.4845	.0269			3.14	.01521	.000845
425	16	.4801	.0300			3.30	.01584	.000990
426	18	.5166	.0287			3.09	.01596	.000887
427	19	.5433	.0285			3.06	.01662	.000872
429	20	.4704	.0235			3.04	.01430	.000714
431	18	.4119	.0228			3.20	.01318	.000732
432	21	.6306	.0300			3.00	.01892	.000900
433	20	.5206	.0260			3.12	.01624	.000811
437	16	.4336	.0271			3.13	.01357	.000848
442	17	.3889	.0228			3.23	.01256	.000736
Average	17.4	.4724	.0270	.0199	1.3666	3.23	.01520	.000874

TABLE 4.—*Analyses of spikes of wheat, arranged according to nitrogen content of kernels. Crop of 1902*—Continued.

3.5 TO 4 PER CENT PROTEID NITROGEN.

Record number.	Number of kernels on row of spikelets.	Weight (in grams) of— Kernels.	Weight (in grams) of— Average kernel.	Volume of average kernel.	Specific gravity of kernels.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in— Kernels.	Proteid nitrogen (gram) in— Average kernel.
174	18	0.4025	0.0223	....	....	3.76	0.01513	0.000838
177	19	.4073	.0214	....	....	3.57	.01454	.000764
179	19	.4972	.0261	....	....	3.85	.01914	.001005
180	17	.5262	.0309	....	....	3.58	.01884	.001110
184	20	.5512	.0275	....	....	3.78	.02084	.001040
186	21	.5414	.0257	....	....	3.97	.02149	.001020
204	15	.4015	.0267	0.0198	1.3460	3.90	.01566	.001043
209	17	.3588	.0211	.0164	1.2828	3.82	.01371	.000806
215	12	.3318	.0276	.0205	1.3493	3.79	.01258	.001046
224	17	.4891	.0287	.0220	1.3039	3.65	.01785	.001048
225	19	.4976	.0261	.0193	1.3507	3.55	.01766	.000927
235	18	.4555	.0253	.0192	1.3164	3.65	.01663	.000923
240	16	.3984	.0249	.0177	1.4025	3.53	.01406	.000879
245	15	.3971	.0264	.0200	1.3230	3.64	.01445	.000961
246	18	.4562	.0253	.0194	1.3058	3.75	.01711	.000949
247	18	.4937	.0274	.0202	1.3561	3.50	.01728	.000959
248	17	.4617	.0271	.0193	1.4095	3.65	.01685	.000991
253	21	.5960	.0283	.0203	1.3917	3.63	.02163	.001327
259	19	.4932	.0259	.0193	1.3400	3.84	.01894	.000995
261	17	.5195	.0305	.0229	1.3333	3.50	.01818	.001068
274	15	.3347	.0223	.0168	1.3300	3.57	.01195	.000796
279	16	.4304	.0269	.0200	1.3441	3.79	.01631	.001020
280	16	.4305	.0269	.0198	1.3600	3.70	.01593	.000995
283	17	.4974	.0292	.0210	1.3911	3.86	.01920	.001127
284	14	.3723	.0265	.0189	1.4050	3.72	.01385	.000986
285	18	.5769	.0320	.0233	1.3715	3.87	.02233	.001238
286	17	.4140	.0243	.0178	1.3660	3.56	.01474	.000865
287	16	.4740	.0296	.0223	1.3270	3.87	.01835	.001146
290	16	.3955	.0247	.0177	1.3921	4.00	.01582	.000988
296	17	.5037	.0296	.0214	1.3832	3.94	.01985	.001166
299	17	.4553	.0267	.0195	1.3715	3.68	.01676	.000983
309	18	.4753	.0239	.0239	1.1051	3.75	.01782	.000990
313	17	.4798	.0282	.0202	1.3971	3.52	.01689	.000993
328	20	.5795	.0289	.0215	1.3466	3.61	.02092	.001043
363	17	.3795	.0223	.0165	1.3499	3.50	.01328	.000781
365	16	.3469	.0216	.0169	1.2787	3.50	.01214	.000756
384	14	.4012	.0286	.0212	1.3499	3.56	.01428	.001020
385	15	.4162	.0277	.0203	1.3670	3.79	.01578	.001050
405	18	.4940	.0274	.0203	1.3508	3.76	.01857	.001030
407	20	.4707	.0235	.0171	1.3700	3.79	.01784	.000891
408	19	.4462	.0234	....	....	3.64	.01624	.000852
409	17	.4329	.0254	....	....	3.59	.01554	.000912
412	16	.3390	.0211	....	....	3.63	.01231	.000766
413	17	.4393	.0258	....	....	3.77	.01656	.000973
417	19	.4530	.0238	....	....	3.80	.01721	.000904
420	17	.4156	.0244	....	....	3.73	.01550	.000910
422	23	.5395	.0234	....	....	3.53	.01904	.000826
435	20	.4310	.0215	....	....	3.53	.01521	.000759
446	17	.4425	.0260	....	....	3.75	.01659	.000975
Average	17.3	.4517	.0257	.01987	1.3494	3.70	.01672	.000982

Table 5 shows at a glance the averages for each of the classes of spikes just tabulated, and permits of a comparison of the average figures for each class.[a]

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[a] The determinations of specific gravity were made by the following method, devised by Prof. S. Avery: A light basket of wire gauze was suspended by a hair from the hook that supported one of the pan hangers of the balance. The basket was allowed to hang in a beaker of benzol supported by a shelf above the pan. By using a counterpoise the balance was now brought to the zero point. The balance was kept at zero by the occasional adjustment of a rider on the left arm of the beam. The wheat was weighed on the pan of the balance, then transferred to the basket and weighed in benzol, and the temperature of the latter carefully noted. The specific gravity was calculated from the well-known formula:

$$\frac{\text{Wt. in air} \times \text{sp. gr. in benzol at T}^{\circ}}{\text{Wt. in air} - \text{wt. in benzol}} = \text{Sp. gr.}$$

TABLE 5.—*Summary of analyses of spikes of wheat, arranged according to nitrogen content of kernels. Crop of 1902.*

Range of percentage of proteid nitrogen.	Percentage of proteid nitrogen in kernels.	Number of—		Weight (in grams) of—		Volume of average kernel.	Specific gravity.	Proteid nitrogen (gram) in—	
		Analyses.	Kernels on row of spikelets.	Kernels.	Average kernel.			Kernels.	Average kernel.
2 to 2.5	2.32	18	17	0.4759	0.0266	0.0209	1.374	0.01141	0.000643
2.5 to 3	2.76	82	17.1	.4791	.0279	.0207	1.368	.01332	.000776
3 to 3.5	3.23	107	17.4	.4724	.0270	.0199	1.367	.01520	.000874
3.5 to 4	3.70	49	17.3	.4715	.0257	.0199	1.349	.01672	.000982

From this table it will be seen that with an increase in the percentage of proteid nitrogen the number of kernels on a row of spikelets remains about constant: that in general there were a decrease in the weight of the kernels on a row of spikelets and a slight decrease in the weight of the average kernel; and that the volume of the average kernel decreased, as did the specific gravity.

It may safely be stated that a high percentage of proteid nitrogen was in these spikes associated with a kernel of low specific gravity, light weight, and small relative volume, and, as the spikes were selected for their ripeness and healthy appearance, this relation can not be attributed to immaturity or disease.

The table last referred to shows a decrease in the weight of the kernels on the spike as the percentage of proteid nitrogen increases; but it also shows that in spite of the decrease in the weight of the kernels there is an increase in the actual amount of proteid nitrogen they contain, and that the same is true of the average kernel.

Table 6 gives a summary of the same analyses, arranged according to the specific gravities of the kernels. All spikes whose kernels had a specific gravity below 1.30 are grouped in one class, those having a specific gravity of 1.30 to 1.33 in another class, and so on until finally all spikes having a specific gravity of more than 1.42 form the last class.

TABLE 6.—*Summary of analyses of spikes of wheat, arranged according to specific gravities of kernels. Crop of 1902.*

Range of specific gravity.	Specific gravity of kernels.	Number of—		Weight of kernels (gram).	Percentage of proteid nitrogen in kernels.	Weight of average kernel (gram).	Proteid nitrogen (gram) in—	
		Analyses.	Kernels				Kernels.	Average kernel.
Below 1.30	1.255	8	16.7	0.3887	3.29	0.02331	0.01280	0.0007662
1.30 to 1.33	1.315	17	16.5	.4315	3.35	.02617	.01446	.0008762
1.33 to 1.36	1.347	50	17.3	.4008	2.91	.02366	.01508	.0008756
1.36 to 1.39	1.375	71	17.2	.4794	3.06	.02786	.01462	.0008559
1.39 to 1.42	1.399	40	16.7	.4848	3.03	.02899	.01459	.0008729
1.42 and over	1.463	8	19.1	.5287	3.07	.02773	.01605	.0008371

This table shows no constant relation between the specific gravity and the number of kernels on the spike. With an increase in the specific gravity there is an increase in the weight of the kernels on the spike, and with some exceptions an increase in the weight of the average kernel. As the specific gravity increases, the percentage of proteid nitrogen decreases, which agrees with the previous table. The grams of proteid nitrogen in the kernels on the spikes and in the average kernel increase with the specific gravity.

Table 7 shows the summary of the same analyses, arranged according to the weight of the average kernel. Spikes whose kernels have an average weight of less than 0.024 gram form the first class, and each succeeding class increases by 0.002 gram.

TABLE 7.—*Summary of analyses of spikes of wheat, arranged according to weight of average kernel. Crop of 1902.*

Range of weight of average kernel (gram).	Weight of average kernel (gram).	Number of—		Weight of kernels (gram).	Specific gravity of kernels.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—	
		Analyses.	Kernels.				Average kernel.	Kernels.
Below 0.024	0.02214	27	16.9	0.3812	1.341	3.197	0.0007184	0.01215
0.024 to 0.026	.02528	38	17.5	.4425	1.361	3.28	.0008294	.01438
0.026 to 0.028	.02705	48	17.0	.4609	1.360	3.22	.0008711	.01475
0.028 to 0.030	.02896	40	17.0	.4916	1.372	3.11	.0009090	.01546
0.030 to 0.032	.03089	26	17.0	.5274	1.388	2.86	.0008787	.01506
0.032 and over	.03324	19	16.8	.5588	1.373	2.88	.0009594	.01617

There seems to be no relation between the weight of the average kernel and the number of kernels on the spike. The weight of all the kernels on the spike naturally increases with the weight of the average kernel. The specific gravity of the kernels increases with the weight of the average kernel. The percentage of proteid nitrogen decreases with an increase in the weight of the average kernel, in which respect it agrees with the two previous tables. The grams of proteid nitrogen in the average kernel and the total proteid nitrogen in the spike increase with the weight of the average kernel.

Samples from each of the spikes of wheat from which these data were derived were planted, together with samples from other spikes, all of which have been analyzed, aggregating 800 in all. Each kernel was planted separately at a distance of 6 inches each way from every other kernel. The kernels from each spike were marked by a stake bearing the record number of the spike.

During the winter a considerable number of plants were killed, so that the stand was irregular in the spring. In some cases all of the plants resulting from a spike of the previous year were killed, and in other cases only a portion of such plants. The result was a somewhat uneven stand, which doubtless gave certain plants an advantage over others in growth and yield.

When the crop was ripe in 1903 each plant was harvested separately, and all of those resulting from spikes which the previous year had shown a proteid nitrogen content of more than 4 per cent or less than 2 per cent were analyzed, as were also a certain number resulting from spikes of intermediate values.

The good kernels on each plant were counted and weighed, thus giving a record of the yield of each plant. From these data the average weight of the kernels per plant was calculated. The specific gravity was not determined and consequently the average volume of the kernels on each plant was not calculated, as was done the previous year.

In Table 8 the plants harvested in 1903 are arranged in classes of 1 to 2 per cent proteid nitrogen, 2 to 2.5 per cent, 2.5 to 3 per cent, 3 to 3.5 per cent, 3.5 to 4 per cent, 4 to 4.5 per cent, and over 4.5 per cent. The number and weight of the kernels on each plant are stated, as is also the average weight of each kernel. The number of grams of proteid nitrogen in all the kernels of the plant is shown, and also the number of grams of proteid nitrogen in the average kernel on each plant. Table 9 shows the average for each class.

These results, so far as they cover the same ground as those of the previous year, have the same significance. They show a quite uniform although slight decrease in the weight of the average kernel accompanying an increase in the percentage of proteid nitrogen, and a very marked increase in the number of grams of proteid nitrogen in the average kernel. Especially marked is the increase in the amount of proteid nitrogen in the average kernel, amounting to 28 per cent of the weight of the kernel for every 1 per cent increase in the content of proteid nitrogen.

One column of this table, not contained in that compiled from results of the previous year, shows the number of grams of proteid nitrogen contained in all of the kernels on the plant; or, in other words, the proteid nitrogen production of the plant. This appears, on the whole, to increase with the percentage of proteid nitrogen, although the results are not sufficiently consistent to permit of an unqualified statement to that effect. The uneven stand of the plants, before referred to, doubtless accounts for these inconsistent results.

Two other columns contain data not obtained in 1902. The first of these shows the number of kernels per plant, which apparently decreases slightly as the percentage of proteid nitrogen increases, but this can not be stated unqualifiedly. The next column shows the weight of kernels per plant, or the yield per plant, which likewise seems to decrease slightly with an increase in the percentage of proteid nitrogen.

TABLE 8.—*Analyses of plants, arranged according to percentage of proteid nitrogen. Crop of 1903.*

1 TO 2 PER CENT PROTEID NITROGEN.

Record number.	Percentage of proteid nitrogen in kernels.	Number of kernels per plant.	Weight (in grams) of—		Total proteid nitrogen in all kernels (gram).	Proteid nitrogen in average kernel (gram).
			Kernels per plant.	Average kernel.		
32206	1.81	507	10.4036	0.02052	0.18831	0.0003714
32605	1.20	225	5.2268	.02323	.06272	.0002788
33407	1.62	305	7.0889	.02271	.11223	.0003679
33408	1.39	77	1.1132	.01446	.01547	.0002009
33905	1.61	508	11.1476	.02194	.17948	.0003533
42206	1.46	25	.3161	.01264	.00462	.0001846
45606	1.91	220	4.0358	.01834	.07708	.0003504
45805	1.84	124	1.5298	.01234	.02815	.0002700
48407	1.50	718	11.2890	.01572	.16933	.0002358
51005	1.34	862	15.5935	.01804	.20881	.0002422
55307	1.89	342	5.6864	.01663	.10747	.0003142
57308	1.69	577	9.8378	.01705	.16626	.0002881
57405	1.98	41	.8328	.02031	.01649	.0004022
57607	1.73	736	16.4433	.02234	.24847	.0003865
58806	1.88	95	1.9469	.02049	.03660	.0003853
60605	1.87	35	.5952	.01701	.01113	.0003180
63505	1.90	208	4.0230	.01934	.07644	.0003674
69806	1.66	558	12.0136	.02153	.19943	.0003574
72606	1.89	543	9.3629	.01724	.18538	.0003414
74305	1.98	216	4.4222	.02047	.08756	.0004054
80305	1.81	729	15.7835	.02165	.28569	.0003919
81705	1.98	465	9.7922	.02106	.19388	.0004170
81710	1.92	396	9.1411	.02308	.17550	.0004432
92407	1.66	53	.8983	.01695	.01491	.0002814
94205	1.65	64	1.2117	.01893	.01999	.0003124
94605	1.95	56	.7319	.01307	.01427	.0002549
94908	1.96	125	2.3678	.01894	.04641	.0003713
95510	1.81	159	2.8356	.01783	.05132	.0003228
Average	1.749	320.3	6.23823	.01871	.10655	.00032914

2 TO 2.5 PER CENT PROTEID NITROGEN.

17405	2.13	738	15.6996	0.02127	0.33441	0.0004531
17408	2.18	497	9.2038	.01852	.20065	.0004037
18805	2.02	137	2.1462	.01567	.04335	.0003164
21212	2.16	84	1.7216	.02050	.03718	.0004427
21705	2.45	58	1.5420	.02659	.03778	.0006514
21707	2.19	582	12.3685	.02125	.27086	.0004654
21708	2.33	390	9.2850	.02381	.21634	.0005547
21709	2.47	361	7.7296	.02141	.19092	.0005289
21912	2.31	510	9.7236	.01907	.22461	.0004404
27205	2.41	891	16.4061	.01841	.39539	.0004437
27206	2.36	777	19.1854	.02469	.45276	.0005827
27306	2.47	684	13.3011	.01945	.32853	.0004803
27505	2.12	539	12.0399	.02183	.24942	.0004627
33107	2.35	318	6.1026	.01919	.14341	.0004510
33405	2.03	421	8.1268	.01930	.16498	.0003919
33605	2.39	301	7.0596	.02345	.16872	.0005605
33606	2.21	382	8.1890	.02144	.18098	.0004738
34208	2.13	156	2.9886	.01916	.06366	.0004081
37706	2.34	56	1.2069	.02155	.02824	.0005053
37906	2.44	19	.2063	.01086	.00503	.0002649
39205	2.11	1,031	21.5399	.02089	.45435	.0004407
39606	2.37	346	4.6383	.01341	.10967	.0003177
44607	2.44	101	1.8246	.01806	.04452	.0004408
48106	2.38	608	11.6655	.01919	.27765	.0004567
48409	2.02	314	6.4302	.02048	.12989	.0004137
55305	2.48	167	2.5160	.01507	.06240	.0003736
55306	2.18	214	4.1323	.01931	.09008	.0004210
55608	2.31	837	22.5848	.02699	.52194	.0006236
55908	2.42	562	12.2210	.02175	.29575	.0005262
55909	2.30	302	9.2120	.03050	.21187	.0007016
56206	2.42	509	9.3093	.01829	.22529	.0004426
56207	2.34	462	10.9073	.02361	.25522	.0005524
57307	2.43	261	4.7117	.01801	.11445	.0004387
57508	2.21	380	12.0728	.03177	.26680	.0007021
58905	2.43	170	2.3031	.01355	.05596	.0003292
59605	2.12	382	7.1828	.01880	.15228	.0003986
59606	2.16	567	9.7084	.01712	.20970	.0003698
63107	2.43	417	9.3120	.02233	.22628	.0005426

TABLE 8.—*Analyses of plants, arranged according to percentage of proteid nitrogen. Crop of 1903*—Continued.

2 TO 2.5 PER CENT PROTEID NITROGEN—Continued.

Record number.	Percentage of proteid nitrogen in kernels.	Number of kernels per plant.	Weight (in grams) of—		Total proteid nitrogen in all kernels (gram).	Proteid nitrogen in average kernel (gram).
			Kernels per plant.	Average kernel.		
63506	2.44	153	2.3986	.01568	0.05853	0.0003825
65306	2.41	544	9.8298	.01807	.23690	.0004355
65307	2.28	373	7.0051	.01878	.15971	.0004282
65308	2.09	583	11.7066	.02008	.24468	.0004197
69505	2.29	225	4.7116	.01847	.10790	.0004231
71905	2.47	1,260	28.2136	.02239	.69688	.0005531
72705	2.13	372	9.1522	.02191	.19936	.0004668
72708	2.27	398	9.0386	.02270	.20518	.0005154
72905	2.48	167	2.6462	.01585	.06563	.0003930
73306	2.45	414	8.5373	.02062	.20918	.0005052
73307	2.39	25	.5572	.02229	.01332	.0005327
74606	2.30	464	9.6451	.02079	.22184	.0004781
76205	2.35	498	8.4407	.01695	.19836	.0003983
81707	2.34	786	18.3614	.02336	.42965	.0005466
81708	2.41	287	7.3993	.02578	.17833	.0006213
81709	2.28	757	16.4692	.02175	.37548	.0004960
84405	2.48	428	8.7448	.02043	.21687	.0005067
84905	2.32	37	.7130	.01927	.01654	.0004471
88608	2.47	74	1.5355	.02075	.03793	.0005125
88609	2.42	470	9.8719	.02100	.23890	.0005082
92409	2.30	315	5.7131	.01814	.13140	.0004171
94209	2.49	190	3.6006	.01895	.08965	.0004719
94406	2.47	549	10.5556	.01923	.26073	.0004749
94407	2.07	419	6.7664	.01615	.14007	.0003343
94905	2.35	286	4.4423	.01553	.10439	.0003650
95509	2.48	138	2.9475	.02136	.07310	.0005297
95707	2.47	52	.7577	.01457	.01872	.0003599
Average	2.319	396.8	8.2502	.020113	.190316	.0004660

2.5 TO 3 PER CENT PROTEID NITROGEN.

17409	2.75	802	14.8957	0.01857	0.40964	0.0005108
17410	2.88	744	16.9987	.02285	.48957	.0006580
20706	2.78	163	3.3138	.02033	.09212	.0005652
20707	2.77	444	9.9070	.02282	.27443	.0006181
20708	2.58	122	2.4690	.02024	.06399	.0005221
20710	2.83	867	17.1115	.01974	.48428	.0005586
21207	2.96	118	2.3066	.01955	.06804	.0005766
21305	2.67	312	6.2514	.02004	.16691	.0005350
21306	2.90	226	4.1516	.01837	.12039	.0005327
21710	2.59	59	.8478	.01437	.02196	.0003722
21711	2.71	873	17.1820	.01968	.46563	.0005334
21805	2.69	1,232	20.9290	.01699	.56299	.0004569
21806	2.71	599	14.2450	.02378	.38604	.0006444
21807	2.73	377	9.4172	.02498	.25709	.0006664
21808	2.57	1,156	19.7446	.01708	.50744	.0004389
21809	2.73	418	8.0214	.01919	.21898	.0005238
21810	2.69	52	1.0304	.01982	.02772	.0005330
21905	2.64	791	14.3111	.01809	.37781	.0004777
22205	2.81	283	2.6965	.00953	.07577	.0002677
22207	2.77	169	3.2787	.01940	.09082	.0005374
25205	2.71	522	10.7836	.02066	.28560	.0005599
25206	2.76	205	4.6754	.02281	.12904	.0006295
26106	2.63	90	2.0737	.02304	.05454	.0006060
26805	2.81	220	4.9456	.02248	.13897	.0006317
26806	2.60	152	2.7255	.01793	.07086	.0004662
26807	2.80	721	17.2324	.02390	.48250	.0006692
26905	2.76	326	6.4102	.01966	.17692	.0005427
26906	2.71	228	4.2376	.01859	.11484	.0005037
26907	2.61	102	1.8276	.01792	.04995	.0004677
26908	2.96	192	3.9797	.02073	.11780	.0006135
26909	2.80	180	2.9999	.01667	.08400	.0004667
27005	2.63	866	16.4120	.01895	.43164	.0004984
27207	2.92	166	3.3266	.02004	.09712	.0005850
27305	2.58	267	5.5666	.02085	.14362	.0005379
27307	2.53	167	3.0850	.01847	.07805	.0004674
27506	2.70	444	10.0005	.02252	.27003	.0006082
27508	2.64	251	5.5324	.02287	.14608	.0006037
27509	2.90	243	5.3615	.02206	.15549	.0006399
28805	2.91	87	2.1851	.02512	.06359	.0007309
32606	2.88	94	2.0162	.02145	.05807	.0006177

TABLE 8.—*Analyses of plants, arranged according to percentage of proteid nitrogen. Crop of 1903*—Continued.

2.5 TO 3 PER CENT PROTEID NITROGEN—Continued.

Record number.	Percentage of proteid nitrogen in kernels.	Number of kernels per plant.	Weight (in grams) of—		Total proteid nitrogen in all kernels (gram).	Proteid nitrogen in average kernel (gram).
			Kernels per plant.	Average kernel.		
33105	2.91	132	2.5601	0.01939	0.07450	0.0005644
33106	2.94	18	.3089	.01716	.00908	.0005045
33406	2.87	283	4.6045	.01627	.13215	.0004670
33906	2.81	119	2.2862	.01921	.06424	.0005399
34205	2.73	464	9.1498	.01972	.24979	.0005383
34207	2.84	611	13.5556	.02219	.38505	.0006273
37305	2.96	309	6.1394	.01987	.18173	.0005881
37705	2.64	461	8.0905	.01972	.23998	.0005327
37707	2.94	193	3.3004	.01710	.09670	.0005010
37905	2.53	37	.9452	.02555	.02391	.0006463
38005	2.84	139	2.5134	.01808	.07138	.0005135
38506	2.89	85	1.6799	.01975	.04855	.0005712
38606	2.63	401	8.4605	.02110	.22251	.0005549
38608	2.82	158	3.0228	.01913	.08522	.0005394
38609	2.74	293	6.7665	.02309	.18540	.0006475
38706	2.59	365	7.2545	.01988	.18789	.0005148
39405	2.88	447	9.3541	.02093	.21399	.0006027
39506	2.93	67	1.9218	.02869	.05631	.0008404
40505	2.82	170	4.1546	.02444	.11716	.0006892
43405	2.92	124	2.8000	.02258	.08176	.0006594
44505	2.94	340	5.9990	.01764	.17637	.0005187
44605	2.86	55	1.1271	.02049	.03223	.0005861
44606	2.90	124	2.5235	.02035	.07318	.0005902
45605	2.82	61	.7081	.01161	.01997	.0003273
46106	2.54	82	1.6103	.01964	.04090	.0004988
46107	2.54	478	8.3935	.01756	.21319	.0004460
48305	2.87	473	12.0278	.02543	.34524	.0007299
48408	2.81	27	.3485	.01291	.00979	.0003627
48507	2.64	70	1.6036	.02296	.04233	.0006062
48508	2.76	603	11.2008	.01858	.30986	.0005127
48805	2.70	547	9.8346	.01798	.26553	.0004877
50706	2.80	35	.4701	.01343	.01316	.0003761
55008	2.60	944	17.4226	.01846	.45299	.0004799
55206	2.56	578	11.3592	.01965	.29079	.0005031
55308	2.54	397	9.5078	.02395	.24150	.0006225
55506	2.80	866	17.8506	.02062	.49995	.0005773
55507	2.63	504	9.8228	.01949	.25834	.0005126
55605	2.64	500	10.9180	.02184	.28823	.0005765
55606	2.58	503	11.0930	.02205	.28580	.0005690
55607	2.69	138	2.3931	.01734	.06437	.0004665
55905	2.67	331	5.7948	.01751	.15470	.0004674
55906	2.81	499	7.9968	.01603	.22471	.0004503
55907	2.59	749	19.3966	.02590	.50238	.0006707
56105	2.73	336	5.7431	.01709	.15679	.0004667
56106	2.57	644	12.0161	.01866	.30881	.0004795
56107	2.96	872	14.4556	.01658	.42790	.0004907
56205	2.51	333	6.5232	.01959	.16373	.0004917
56208	2.61	563	13.5720	.02356	.34616	.0006149
56209	2.59	950	15.8086	.01664	.40945	.0004310
57005	2.71	88	1.5364	.01746	.04164	.0004731
57006	2.76	701	10.1836	.01453	.28107	.0004010
57007	2.65	168	3.3176	.01975	.08792	.0005233
57105	2.76	407	3.7263	.00916	.10285	.0002527
57306	2.86	434	7.9772	.01838	.22815	.0005257
57406	2.75	135	2.4923	.01846	.06854	.0005077
57407	2.62	762	14.9992	.01968	.39297	.0005157
57408	2.61	596	12.2004	.02047	.31842	.0005343
57506	2.80	180	2.7616	.01534	.07733	.0004296
57507	2.85	359	6.9861	.01946	.19905	.0005545
57509	2.54	611	10.6261	.01739	.26990	.0004417
57606	2.74	132	3.0790	.02333	.08436	.0006391
57608	2.64	438	8.6189	.01968	.22756	.0005195
57805	2.87	270	4.8988	.01814	.14060	.0005207
58206	2.67	148	1.3961	.00943	.03728	.0002519
58505	2.95	273	7.4516	.02730	.21982	.0008052
58805	2.74	1,158	23.1471	.01999	.63422	.0005464
63106	2.79	165	3.3006	.02001	.09208	.0005581
66005	2.63	370	7.6690	.02073	.20170	.0005451
69506	2.50	663	13.5696	.02047	.33923	.0005117
69705	2.50	244	3.7810	.01550	.09453	.0003874
72406	2.95	430	8.2929	.01929	.24464	.0005689
73308	2.92	624	14.2986	.02291	.41752	.0006539
74506	2.73	23	.4096	.01781	.01118	.0004862
74508	2.60	57	.8172	.01434	.02125	.0003728
74605	2.60	399	7.1181	.01784	.18507	.0004638

TABLE 8.—*Analyses of plants, arranged according to percentage of proteid nitrogen. Crop of 1903*—Continued.

2.5 TO 3 PER CENT PROTEID NITROGEN—Continued.

Record number.	Percentage of proteid nitrogen in kernels.	Number of kernels per plant.	Weight (in grams) of—		Total proteid nitrogen in all kernels (gram).	Proteid nitrogen in average kernel (gram).
			Kernels per plant.	Average kernel.		
74607........	2.56	491	8.3406	0.01699	0.21352	0.0004349
81405........	2.62	240	4.5737	.01862	.11710	.0004879
81505........	2.94	146	2.8327	.01940	.08328	.0005704
81706........	2.71	722	15.3928	.02132	.41715	.0005778
85205........	2.60	214	3.4766	.01625	.09039	.0004224
85206........	2.66	376	4.9315	.01312	.13118	.0003332
86105........	2.56	203	3.0282	.01495	.07964	.0003923
86106........	2.63	436	7.6241	.01749	.20052	.0004599
88605........	2.80	69	1.6362	.02731	.04581	.0007640
88606........	2.53	481	9.9456	.02068	.25162	.0005231
88607........	2.61	234	5.1584	.02205	.13463	.0005754
88905........	2.83	293	5.3069	.01811	.15019	.0005126
88906........	2.65	546	9.9034	.01814	.26245	.0004807
91906........	2.81	200	3.5486	.01774	.09972	.0004986
92205........	2.74	345	5.2616	.01525	.14417	.0004179
92206........	2.67	46	1.1074	.02407	.02957	.0006428
92207........	2.55	209	3.6926	.01767	.09416	.0004505
92208........	2.72	353	6.6206	.01876	.18008	.0005102
92305........	2.93	160	2.3859	.01491	.06991	.0004369
92408........	2.97	207	3.7820	.01827	.11233	.0005426
92507........	2.58	505	9.6779	.01916	.24969	.0004944
94206........	2.78	402	7.5006	.01866	.20851	.0005187
94207........	2.86	718	13.7057	.01909	.39199	.0005460
94907........	2.94	626	12.1918	.01948	.35844	.0005726
95505........	2.81	37	.3146	.00850	.00884	.0002389
95506........	2.74	597	11.0548	.01852	.30291	.0005074
95507........	2.59	571	12.1592	.02030	.31492	.0005515
95508........	2.56	740	14.4617	.01954	.37023	.0005003
95705........	2.54	636	10.3426	.01626	.26270	.0004131
95706........	2.73	267	5.1629	.01934	.14095	.0005279
Average	2.731	370.36	7.1755	.019354	.194423	.00052706

3 TO 3.5 PER CENT PROTEID NITROGEN.

17305........	3.03	183	3.6302	0.01984	0.10999	0.0006010
17306........	3.09	243	3.9968	.01645	.12350	.0005082
17307........	3.46	138	3.1454	.02280	.10883	.0007886
17308........	3.25	61	1.2275	.02012	.03994	.0006540
17406........	3.29	124	2.0907	.01683	.06878	.0005547
18906........	3.48	65	.9229	.01420	.03212	.0004941
20705........	3.09	109	1.8517	.01698	.05722	.0005249
20709........	3.05	258	5.3229	.02063	.16235	.0006292
20805........	3.32	697	14.6942	.02157	.48784	.0006999
21205........	3.16	123	2.3642	.01922	.07471	.0006074
21208........	3.24	287	5.1594	.01798	.16712	.0005824
21211........	3.15	10	.2806	.02806	.00884	.0008839
21307........	3.04	143	2.5691	.01796	.07810	.0005461
21308........	3.45	354	5.8080	.01641	.20038	.0005660
21906........	3.18	408	10.4800	.02563	.33403	.0008168
21907........	3.35	158	2.9248	.01851	.09798	.0006201
21913........	3.01	492	10.1925	.02072	.30680	.0006235
22206........	3.22	146	2.5712	.01720	.08086	.0005538
22208........	3.18	118	1.9090	.01619	.06071	.0005144
22210........	3.17	298	6.0173	.02019	.19075	.0006401
22211........	3.17	561	11.5675	.02062	.36671	.0006537
26105........	3.02	131	1.8242	.01393	.05508	.0003662
26808........	3.09	222	3.8811	.01748	.11992	.0005402
27507........	3.08	75	1.3746	.01833	.04234	.0005646
28206........	3.07	219	4.3698	.01996	.13415	.0006126
28806........	3.02	685	14.4630	.02111	.43679	.0006376
32207........	3.48	69	1.2573	.01822	.04375	.0006341
33305........	3.41	150	3.1346	.02090	.10689	.0007126
33607........	3.22	136	2.8903	.02125	.09307	.0006843
34606........	3.12	280	6.1962	.02213	.19332	.0006904
39507........	3.02	111	1.8862	.01699	.05696	.0005132
40305........	3.11	179	3.6003	.02011	.11197	.0006255
40405........	3.17	46	.6316	.01373	.02002	.0004352
42405........	3.07	66	1.4892	.02251	.04572	.0006927
42905........	3.17	67	1.2499	.01866	.03650	.0005447
46105........	3.00	260	4.6146	.01775	.13843	.0005324
48306........	3.29	157	2.6571	.01692	.08742	.0005568

TABLE 8.—*Analyses of plants, arranged according to percentage of proteid nitrogen. Crop of 1903*—Continued.

3 TO 3.5 PER CENT PROTEID NITROGEN—Continued.

Record number.	Percentage of proteid nitrogen in kernels.	Number of kernels per plant.	Weight (in grams) of—		Total proteid nitrogen in all kernels (gram).	Proteid nitrogen in average kernel (gram).
			Kernels per plant.	Average kernel.		
48405	3.31	76	0.9701	0.01276	0.03211	0.0004225
48506	3.20	556	9.4585	.01701	.30267	.0005444
48705	3.13	264	4.3615	.01652	.13652	.0005171
48706	3.00	379	6.1986	.01635	.18596	.0004906
49505	3.24	67	1.2716	.01898	.04120	.0006149
50905	3.30	221	2.3982	.01085	.07914	.0003581
55005	3.05	393	7.9684	.02028	.24304	.0006185
55006	3.16	451	7.1852	.01593	.22705	.0005034
55205	3.10	40	.6893	.01723	.02137	.0005342
55508	3.11	216	3.7407	.01732	.11636	.0005386
57305	3.19	501	8.5777	.01666	.29188	.0005326
57905	3.18	221	2.4731	.01118	.07859	.0003556
58207	3.09	307	4.2207	.01375	.13042	.0004248
58705	3.01	235	2.5436	.01082	.07656	.0003256
62805	3.25	111	1.3451	.01212	.04272	.0003938
63105	3.24	90	1.5452	.01717	.05007	.0005563
72405	3.36	213	8.4415	.03963	.28363	.0013316
72707	3.49	225	4.5806	.02036	.15986	.0007105
72806	3.01	110	2.0970	.01906	.06312	.0005738
74507	3.02	493	9.2130	.01869	.27823	.0005644
81406	3.31	72	1.2391	.01721	.04101	.0005697
84906	3.43	382	7.5438	.01975	.25873	.0006773
91305	3.21	138	3.0940	.02242	.09932	.0007197
91905	3.36	198	3.4436	.01739	.11570	.0005844
92405	3.10	214	3.4356	.01605	.10650	.0004977
92406	3.11	380	8.2366	.02168	.25616	.0006741
92505	3.00	156	2.6615	.01706	.07985	.0005118
94208	3.10	322	3.7828	.01175	.11727	.0003642
94906	3.41	685	12.3862	.01808	.42236	.0006166
Average	3.184	235.5	4.38558	.018366	.139656	.00058156

3.5 TO 4 PER CENT PROTEID NITROGEN.

17506	3.52	93	2.2881	0.02460	0.08044	0.0008660
17507	3.80	43	.7220	.01795	.02933	.0006822
18905	3.81	103	1.4864	.01443	.05663	.0005498
21209	3.61	89	1.4484	.01627	.05228	.0005875
21811	3.75	567	11.9114	.02101	.44666	.0007877
21908	3.82	173	3.5574	.02056	.13589	.0007855
22209	3.84	31	.4336	.01399	.01665	.0005371
26107	3.92	144	2.0390	.01416	.07993	.0005551
32608	3.78	55	1.0183	.01851	.03849	.0006998
34206	3.73	81	1.5940	.01968	.05946	.0007340
36905	3.88	267	5.0200	.01880	.19478	.0007295
38505	3.61	563	12.1088	.02252	.43713	.0007764
42205	3.63	94	1.8494	.01967	.06713	.0007142
45005	3.58	235	3.2340	.01376	.11575	.0004927
48505	3.66	137	1.9154	.01398	.07010	.0005117
49905	3.62	23	.6760	.02939	.02436	.0010640
50705	3.54	30	.5958	.01986	.02109	.0007032
50906	3.57	114	1.7280	.01516	.06169	.0005411
66006	3.54	366	6.0090	.01642	.21272	.0005812
66008	3.59	174	3.1555	.01814	.11328	.0006510
72706	3.86	591	14.6802	.02484	.56666	.0009588
94909	3.60	218	3.6977	.01696	.13312	.0006106
Average	3.69	190.5	3.68947	.018666	.13698	.00068723

TABLE 8.—*Analyses of plants, arranged according to percentage of proteid nitrogen. Crop of 1903*—Continued.

4 TO 4.5 PER CENT PROTEID NITROGEN.

Record number.	Percentage of proteid nitrogen in kernels.	Number of kernels per plant.	Weight (in grams) of— Kernels per plant.	Weight (in grams) of— Average kernel.	Total proteid nitrogen in all kernels (gram).	Proteid nitrogen in average kernel (gram).
21812	4.26	983	14.8139	0.01507	0.63107	0.0006420
21813	4.04	216	4.0258	.01877	.16377	.0007582
21909	4.43	525	12.1819	.02317	.53889	.0010265
27308	4.15	254	4.5123	.01777	.18726	.0007373
34405	4.33	207	4.1281	.01994	.17875	.0008635
43505	4.13	93	1.4464	.01555	.05974	.0006423
45705	4.18	44	.7532	.01712	.03148	.0007155
55007	4.21	118	2.1571	.01828	.09082	.0007696
69305	4.42	103	2.0430	.01984	.09030	.0008767
76206	4.45	447	5.4411	.01217	.24213	.0005417
92506	4.39	229	3.8709	.01690	.16993	.0007421
Average	4.27	292.6	5.03397	.017689	.21674	.00075594

MORE THAN 4.5 PER CENT PROTEID NITROGEN

17505	4.70	29	0.3885	0.01340	0.01826	0.0006296
21206	5.23	149	2.8564	.01917	.14939	.0010026
21210	5.03	237	3.9143	.01578	.19689	.0007934
21706	4.71	807	19.3318	.02390	.91052	.0011283
21911	5.48	383	8.4593	.02209	.46356	.0012103
38605	5.85	61	1.2124	.01988	.07093	.0011627
38607	4.55	19	.3037	.01598	.01382	.0007273
40205	4.69	194	3.6302	.01871	.17026	.0008776
48406	4.87	249	3.2964	.01324	.16053	.0006447
65305	4.92	78	1.8018	.02310	.08865	.0011365
69805	5.82	110	2.4420	.02220	.14213	.0012921
72605	4.65	65	1.1166	.01718	.05192	.0007988
72607	5.59	188	3.4442	.01832	.19253	.0010241
92306	4.93	347	6.0091	.01732	.29625	.0008539
Average	5.07	208.28	4.15727	.01859	.208974	.0009487

TABLE 9.—*Summary of analyses of plants, arranged according to percentage of proteid nitrogen. Crop of 1903.*

Range of percentage of proteid nitrogen.	Percentage of proteid nitrogen in kernels.	Number of— Analyses.	Number of— Kernels.	Weight (in grams) of— Kernels.	Weight (in grams) of— Average kernel.	Proteid nitrogen (in grams) in— All kernels.	Proteid nitrogen (in grams) in— Average kernel.
1 to 2	1.749	28	320.3	6.2382	0.01871	0.10655	0.0003291
2 to 2.5	2.32	65	396	8.2502	.02011	.19032	.0004660
2.5 to 3	2.73	145	370	7.1755	.01935	.19442	.0005271
3 to 3.5	3.18	66	235	4.3856	.01837	.13966	.0005816
3.5 to 4	3.69	22	190	3.6895	.01867	.13698	.0006872
4 to 4.5	4.27	11	292	5.0340	.01769	.21674	.0007559
4.5 and over	5.07	14	208	4.1573	.01859	.20897	.0009487

Table 10 shows the analyses of the crop of 1903 arranged on the basis of weight of average kernel. Determinations of gliadin and glutenin were made in these analyses and the sums of these are inserted in this table.[a] All plants having an average kernel weight of less than 0.010 gram form the first class and each succeeding class increases by 0.002 gram. Table 11 is a summary of these analyses.

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[a] Determinations of gliadin and glutenin were made by methods practically the same as those described by Prof. Harry Snyder in Bulletin No. 63 of the Minnesota Experiment Station, except that smaller quantities were used.

TABLE 10.—*Analyses of plants, arranged according to weight of average kernel. Crop of 1903.*

WEIGHT OF AVERAGE KERNEL, 0.000 TO 0.010 GRAM.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—		Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in—	
					Average kernel.	Kernels on plant.		Average kernel.	Kernels on plant.
22205.....	0.00953	283	2.6965	2.81	0.0002677	0.07577	1.97	0.0001877	0.05312
57105.....	.00916	407	3.7263	2.76	.0002527	.10285	....	....	....
58206.....	.00943	148	1.3961	2.67	.0002519	.03728	....	....	....
95505.....	.00850	37	.3146	2.81	.0002389	.00884	....	....	....
Average.	.00915	219	2.0334	2.76	.0002528	.05618	1.97	.0001877	.05312

WEIGHT OF AVERAGE KERNEL, 0.010 TO 0.012 GRAM.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel.	Proteid nitrogen in kernels on plant.	Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in kernels on plant.
37906.....	0.01086	19	0.2063	2.44	0.0002649	0.00503	....	....	....
45605.....	.01161	61	.7081	2.82	.0003273	.01997	....	....	....
50905.....	.01085	221	2.3982	3.30	.0003581	.07914	....	....	....
57905.....	.01118	221	2.4731	3.18	.0003556	.07859	2.92	0.0003264	0.07221
58705.....	.01082	235	2.5436	3.01	.0003258	.07656	2.47	.0002673	.06283
94208.....	.01175	322	3.7828	3.10	.0003642	.11727	....	....	....
Average.	.01118	179	2.0187	2.98	.0003326	.06276	2.69	.0002968	.06752

WEIGHT OF AVERAGE KERNEL, 0.012 TO 0.014 GRAM.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel.	Proteid nitrogen in kernels on plant.	Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in kernels on plant.
17505.....	0.01340	29	0.3885	4.70	0.0006296	0.01826	....	....	....
22209.....	.01399	31	.4336	3.84	.0005371	.01665	....	....	....
26105.....	.01393	131	1.8242	3.02	.0003662	.05508	....	....	....
39606.....	.01341	346	4.6383	2.37	.0003177	.10967	....	....	....
40405.....	.01373	46	.6316	3.17	.0004352	.02002	....	....	....
42206.....	.01264	25	.3161	1.46	.0001846	.00462	....	....	....
45005.....	.01376	235	3.2340	3.58	.0004927	.11575	1.36	0.0001871	0.04398
45805.....	.01234	124	1.5298	1.84	.0002700	.02815	....	....	....
48405.....	.01276	76	.9701	3.31	.0004225	.03211	....	....	....
48406.....	.01324	249	3.2964	4.87	.0006447	.16053	2.25	.0002979	.08168
48408.....	.01291	27	.3485	2.81	.0003627	.00979	....	....	....
48505.....	.01398	137	1.9154	3.66	.0005117	.07010	1.76	.0002460	.03371
50706.....	.01343	35	.4701	2.80	.0003761	.01316	....	....	....
58207.....	.01375	307	4.2207	3.09	.0004248	.13042	2.49	.0003424	.10510
58905.....	.01355	170	2.3031	2.43	.0003292	.05596	....	....	....
62805.....	.01212	111	1.3451	3.25	.0003938	.04272	....	....	....
76206.....	.01217	447	5.4411	4.45	.0005417	.24213	2.03	.0002471	.11046
85206.....	.01312	376	4.9315	2.66	.0003332	.13118	....	....	....
94605.....	.01307	56	.7319	1.95	.0002549	.01427	....	....	....
Average.	.01323	155.7	2.0510	3.12	.0004120	.06687	1.98	.0002641	.07499

WEIGHT OF AVERAGE KERNEL, 0.014 TO 0.016 GRAM.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel.	Proteid nitrogen in kernels on plant.	Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in kernels on plant.
18805.....	0.01567	137	2.1462	2.02	0.0003164	0.04335	....	....	....
18905.....	.01443	103	1.4864	3.81	.0005498	.05663	1.54	0.0003218	0.03315
18906.....	.01420	65	.9229	3.48	.0004941	.03212	....	....	....
21210.....	.01577	237	3.9143	5.03	.0007934	.19689	1.34	.0002113	.05245
21710.....	.01437	59	.8478	2.59	.0003722	.02196	....	....	....
21812.....	.01507	983	14.8139	4.26	.0006420	.63107	2.02	.0003044	.29934
26107.....	.01416	144	2.0390	3.92	.0005551	.07993	1.35	.0001912	.02753
33408.....	.01446	77	1.1132	1.39	.0002009	.01547	....	....	....
38607.....	.01598	19	.3037	4.55	.0007273	.01382	....	....	....
43505.....	.01555	93	1.4464	4.13	.0006423	.05974	....	....	....
48407.....	.01572	718	11.2890	1.50	.0002358	.16933	....	....	....
50906.....	.01516	114	1.7280	3.57	.0005411	.06169	....	....	....
55006.....	.01593	451	7.1852	3.16	.0005034	.22705	1.75	.0002788	.12574
55305.....	.01507	167	2.5160	2.48	.0003736	.06240	1.97	.0002969	.04957
57006.....	.01453	701	10.1836	2.76	.0004010	.28107	....	....	....

TABLE 10.—*Analyses of plants, arranged according to weight of average kernel. Crop of 1903*—Continued.

WEIGHT OF AVERAGE KERNEL, 0.014 TO 0.016 GRAM—Continued.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—		Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in—	
					Average kernel.	Kernels on plant.		Average kernel.	Kernels on plant.
57506	0.01534	180	2.7616	2.80	0.0004296	0.07733	2.34	0.0003590	0.06462
63506	.01568	153	2.3986	2.44	.0003825	.05853			
69705	.01550	244	3.7810	2.50	.0003874	.09453			
72905	.01585	167	2.6462	2.48	.0003930	.06563			
74508	.01434	57	.8172	2.60	.0003728	.02125			
86105	.01495	203	3.0282	2.56	.0003923	.07964			
92205	.01525	345	5.2616	2.74	.0004179	.14417			
92305	.01491	160	2.3859	2.93	.0004369	.06991			
92905	.01534	176	2.7000	3.50	.0005369	.09450			
92906	.01592	181	2.8816	2.99	.0004760	.08616			
94905	.01553	286	4.4423	2.35	.0003650	.10439			
95707	.01457	52	.7577	2.47	.0003599	.01872			
Average	.01516	232	3.5480	3.00	.0004555	.10619	1.76	.0002805	.09320

WEIGHT OF AVERAGE KERNEL, 0.016 TO 0.018 GRAM.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—		Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in—	
					Average kernel.	Kernels on plant.		Average kernel.	Kernels on plant.
17306	0.01645	243	3.9968	3.09	0.0005082	0.12350			
17406	.01686	124	2.0907	3.29	.0005547	.06878			
17507	.01795	43	.7720	3.80	.0006822	.02934			
20705	.01698	109	1.8517	3.09	.0005249	.05722			
21208	.01798	287	5.1594	3.24	.0005824	.16712	2.15	0.0003865	0.11093
21209	.01627	89	1.4484	3.61	.0005875	.05228			
21307	.01796	143	2.5691	3.04	.0005461	.07810			
21308	.01641	354	5.8080	3.45	.0005660	.20038			
21805	.01699	1,232	20.9290	2.69	.0004569	.56299			
21808	.01708	1,156	19.7446	2.57	.0004389	.50744	1.96	.0003348	.38700
22206	.01720	146	2.5712	3.22	.0005538	.08086	2.11	.0003629	.05425
22208	.01619	118	1.9090	3.18	.0005144	.06071	2.14	.0003465	.04084
26806	.01793	152	2.7255	2.60	.0004662	.07086			
26808	.01748	222	3.8811	3.09	.0005402	.11992	2.28	.0003985	.08849
26907	.01792	102	1.8276	2.61	.0004677	.04995			
26909	.01667	180	2.9999	2.80	.0004667	.08400	1.88	.0003134	.05640
27308	.01777	254	4.5123	4.15	.0007373	.18726			
33106	.01716	18	.3089	2.94	.0005045	.00908			
33406	.01627	283	4.6045	2.87	.0004670	.13215			
37707	.01710	193	3.3004	2.93	.0005010	.09670	2.10	.0003591	.06931
39507	.01699	111	1.8862	3.02	.0005132	.05696			
44505	.01764	340	5.9990	2.94	.0005187	.17637			
45705	.01712	44	.7532	4.18	.0007155	.03148			
46105	.01775	260	4.6146	3.00	.0005324	.13843			
46107	.01756	478	8.3935	2.54	.0004460	.21319	2.08	.0003652	.17458
48306	.01692	157	2.6571	3.29	.0005568	.08742	2.13	.0003604	.05660
48506	.01701	556	9.4585	3.20	.0005444	.30267	2.17	.0003691	.20525
48705	.01652	264	4.3615	3.13	.0005171	.13652	1.56	.0002577	.06804
48706	.01635	379	6.1986	3.00	.0004906	.18596			
48806	.01798	547	9.8346	2.70	.0004877	.26553			
55205	.01723	40	.6893	3.10	.0005342	.02137			
55307	.01663	342	5.6864	1.89	.0003142	.10747	1.56	.0002594	.08871
55508	.01732	216	3.7407	3.11	.0005386	.11636	1.96	.0003395	.07332
55607	.01734	138	2.3931	2.69	.0004665	.06437			
55905	.01751	331	5.7948	2.67	.0004674	.15470	1.75	.0003064	.10141
55906	.01603	499	7.9968	2.81	.0004503	.22471	1.47	.0002356	.11755
56105	.01709	336	5.7431	2.73	.0004667	.15679	2.12	.0003622	.12175
56107	.01658	872	14.4556	2.96	.0004907	.42790	2.23	.0003697	.32236
56209	.01664	950	15.8086	2.59	.0004310	.40945	2.21	.0003677	.34937
57005	.01746	88	1.5364	2.71	.0004731	.04164	2.09	.0003649	.03211
57305	.01666	501	8.5777	3.19	.0005826	.29188			
57308	.01705	577	9.8378	1.69	.0002881	.16626			
57509	.01739	611	10.6261	2.54	.0004417	.26990			
59606	.01712	567	9.7084	2.16	.0003698	.20970			
60605	.01701	35	.5952	1.87	.0003180	.01113			
63105	.01717	90	1.5452	3.24	.0005563	.05007			
66006	.01642	366	6.0090	3.54	.0005812	.21272	1.38	.0002266	.08292

TABLE 10.—*Analyses of plants, arranged according to weight of average kernel. Crop of 1903*—Continued.

WEIGHT OF AVERAGE KERNEL, 0.016 TO 0.018 GRAM—Continued.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in— Average kernel.	Proteid nitrogen (gram) in— Kernels on plant.	Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in— Average kernel.	Gliadin-plus-glutenin nitrogen (gram) in— Kernels on plant.
72605.....	0.01718	65	1.1166	4.65	0.0007988	0.05192	....	....	....
72606.....	.01724	543	9.3629	1.89	.0003414	.18538	....	....	....
74506.....	.01781	23	.4096	2.73	.0004862	.01118	....	....	....
74605.....	.01784	399	7.1181	2.60	.0004638	.18507	....	....	....
74607.....	.01699	491	8.3406	2.56	.0004349	.21352	....	....	....
76205.....	.01695	498	8.4407	2.35	.0003983	.19836	....	....	....
81406.....	.01721	72	1.2391	3.31	.0005697	.04101	....	....	....
85205.....	.01625	214	3.4766	2.60	.0004224	.09039	....	....	....
86106.....	.01749	436	7.6241	2.63	.0004599	.20052	....	....	....
91905.....	.01739	198	3.4436	3.36	.0005844	.11570	....	....	....
91906.....	.01774	200	3.5486	2.81	.0004986	.09972	....	....	....
92207.....	.01767	209	3.6926	2.55	.0004505	.09416	....	....	....
92306.....	.01732	347	6.0091	4.93	.0008539	.29625	4.06	0.0007032	0.24397
92405.....	.01605	214	3.4356	3.10	.0004977	.10650	....	....	....
92407.....	.01695	53	.8983	1.66	.0002814	.01491	....	....	....
92505.....	.01706	156	2.6615	3.00	.0005118	.07985	....	....	....
92506.....	.01690	229	3.8709	4.39	.0007421	.16993	....	....	....
92908.....	.01732	187	3.2388	2.32	.0004018	.07514	....	....	....
94407.....	.01615	419	6.7664	2.07	.0003343	.14007	....	....	....
94909.....	.01696	218	3.6977	3.60	.0005106	.13312	....	....	....
95510.....	.01783	159	2.8356	1.81	.0003228	.05132	....	....	....
95705.....	.01626	636	10.3426	2.54	.0004131	.26270	....	....	....
Average	.01709	305.9	5.2055	2.93	.0005020	.14618	2.07	.0003519	.13548

WEIGHT OF AVERAGE KERNEL, 0.018 TO 0.020 GRAM.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in— Average kernel.	Proteid nitrogen (gram) in— Kernels on plant.	Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in— Average kernel.	Gliadin-plus-glutenin nitrogen (gram) in— Kernels on plant.
17305.....	0.01984	183	3.6302	3.03	0.0006010	0.10999	....	....	....
17408.....	.01852	497	9.2038	2.18	.0004037	.20065	....	....	....
17409.....	.01857	802	14.8957	2.75	.0005108	.40964	....	....	....
20710.....	.01974	867	17.1115	2.83	.0005586	.48428	2.00	0.0003948	0.34222
21205.....	.01922	123	2.3642	3.16	.0006074	.07471	....	....	....
21206.....	.01917	149	2.8564	5.23	.0010026	.14939	....	....	....
21207.....	.01955	118	2.3066	2.96	.0005766	.06804	....	....	....
21306.....	.01837	226	4.1516	2.90	.0005327	.12039	....	....	....
21711.....	.01968	873	17.1820	2.71	.0005334	.46563	....	....	....
21809.....	.01919	418	8.0214	2.73	.0005238	.21898	2.18	.0004183	.17487
21810.....	.01982	52	1.0304	2.69	.0005330	.02772	....	....	....
21813.....	.01877	216	4.0258	4.04	.0007582	.16377	2.14	.0004017	.08615
21905.....	.01809	791	14.3111	2.64	.0004777	.37781	2.18	.0003944	.31198
21907.....	.01851	158	2.9248	3.35	.0006201	.09798	2.15	.0003980	.06288
21912.....	.01907	510	9.7236	2.31	.0004404	.22461	....	....	....
22207.....	.01940	169	3.2787	2.77	.0005374	.09082	1.82	.0003531	.05967
26905.....	.01966	326	6.4102	2.76	.0005427	.17692	2.09	.0004109	.13398
26906.....	.01859	228	4.2376	2.71	.0005037	.11484	1.82	.0003383	.07712
27005.....	.01895	866	16.4120	2.63	.0004984	.43164	1.90	.0003600	.31182
27205.....	.01841	891	16.4061	2.41	.0004437	.39539	1.70	.0003130	.27890
27306.....	.01945	684	13.3011	2.47	.0004803	.32853	....	....	....
27307.....	.01847	167	3.0850	2.53	.0004674	.07805	....	....	....
27507.....	.01833	75	1.3746	3.08	.0005646	.04234	....	....	....
28206.....	.01996	219	4.3698	3.07	.0006126	.13415	2.42	.0004830	.10575
32207.....	.01822	69	1.2573	3.48	.0006341	.04375	....	....	....
32608.....	.01851	55	1.0183	3.78	.0006998	.03849	....	....	....
33105.....	.01939	132	2.5601	2.91	.0005644	.07450	3.50	.0006787	.07450
33107.....	.01919	318	6.1026	2.35	.0004510	.14341	1.92	.0004163	.12643
33405.....	.01930	421	8.1268	2.03	.0003919	.16498	....	....	....
33906.....	.01921	119	2.2862	2.81	.0005399	.06424	....	....	....
34205.....	.01972	464	9.1498	2.73	.0005383	.24979	....	....	....
34206.....	.01968	81	1.5940	3.73	.0007340	.05946	....	....	....
34208.....	.01916	156	2.9886	2.13	.0004081	.06366	....	....	....
34405.....	.01994	207	4.1281	4.33	.0008635	.17875	2.44	.0004865	.10073
36905.....	.01880	267	5.0200	3.88	.0007295	.19478			
37305.....	.01987	309	6.1394	2.96	.0005881	.18173	2.29	.0004550	.14060
37705.....	.01972	461	8.0905	2.64	.0005327	.23998	1.26	.0002485	.10194
38005.....	.01808	139	2.5134	2.84	.0005135	.07138	1.23	.0002224	.03091
38506.....	.01975	85	1.6799	2.89	.0005712	.04855	....	....	....
38605.....	.01987	61	1.2124	5.85	.0011627	.07093	....	....	....
38608.....	.01913	158	3.0228	2.82	.0005394	.08522	1.73	.0003309	.05229
38706.....	.01988	365	7.2545	2.59	.0005148	.18789	....	....	....
40205.....	.01871	194	3.6302	4.69	.0008776	.17026	3.07	.0005744	.11145

TABLE 10.—*Analyses of plants, arranged according to weight of average kernel. Crop of 1903*—Continued.

WEIGHT OF AVERAGE KERNEL, 0.018 TO 0.020 GRAM—Continued.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—		Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in—	
					Average kernel.	Kernels on plant.		Average kernel.	Kernels on plant.
42205	0.01967	94	1.8494	3.63	0.0007142	0.06713	2.73	0.0005370	0.05049
42905	.01866	67	1.2499	3.17	.0005447	.03650	....	....	....
44607	.01806	101	1.8246	2.44	.0004408	.04452	....	....	....
45606	.01834	220	4.0358	1.91	.0003504	.07708	....	....	....
46106	.01964	82	1.6103	2.54	.0004988	.04090	....	....	....
48106	.01919	608	11.6655	2.38	.0004567	.27765	1.80	.0003454	.20997
48508	.01858	603	11.2008	2.76	.0005127	.30986	....	....	....
49505	.01898	67	1.2716	3.24	.0006149	.04120	....	....	....
50705	.01986	30	.5958	3.54	.0007032	.02109	....	....	....
51005	.01804	862	15.5835	1.34	.0002422	.20881	....	....	....
55007	.01828	118	2.1571	4.21	.0007696	.09082	2.21	.0004040	.04767
55008	.01846	944	17.4226	2.60	.0004799	.45299	1.58	.0002917	.27528
55206	.01965	578	11.3592	2.56	.0005031	.29079	1.87	.0003675	.21241
55306	.01931	214	4.1323	2.18	.0004210	.09008	....	....	....
55507	.01949	504	9.8228	2.63	.0005126	.25834	2.07	.0004034	.20333
56106	.01866	644	12.0161	2.57	.0004795	.30881	2.09	.0003900	.25114
56205	.01959	333	6.5232	2.51	.0004917	.16373	1.85	.0003624	.12068
56206	.01829	509	9.3093	2.42	.0004426	.22529	1.95	.0003566	.18153
57007	.01975	168	3.3176	2.65	.0005233	.08792	....	....	....
57306	.01838	434	7.9772	2.86	.0005257	.22815	....	....	....
57307	.01801	261	4.7117	2.43	.0004387	.11445	....	....	....
57405	.01846	135	2.4923	2.75	.0005077	.06854	2.13	.0003932	.05309
57407	.01968	762	14.9992	2.62	.0005157	.39297	1.86	.0003660	.27898
57507	.01946	359	6.9861	2.85	.0005545	.19905	1.55	.0003016	.10828
57608	.01968	438	8.6189	2.64	.0005195	.22756	....	....	....
57805	.01814	270	4.8988	2.87	.0005207	.14060	2.68	.0004861	.13126
58805	.01999	1,158	23.1471	2.74	.0005464	.63422	2.11	.0004218	.48839
59505	.01880	382	7.1828	2.12	.0003986	.15228	....	....	....
63505	.01934	208	4.0230	1.90	.0003674	.07644	....	....	....
65306	.01807	544	9.8298	2.41	.0004282	.23690	1.68	.0003036	.16514
65307	.01878	373	7.0051	2.28	.0004355	.15971	1.81	.0003399	.12680
66008	.01814	174	3.1555	3.59	.0006510	.11328	....	....	....
69305	.01984	103	2.0430	4.42	.0008767	.09030	....	....	....
69505	.01847	255	4.7116	2.29	.0004231	.10790	....	....	....
72406	.01929	430	8.2929	2.95	.0005689	.24464	....	....	....
72607	.01832	188	3.4442	5.59	.0010241	.19253	2.51	.0004598	.08645
72806	.01906	110	2.0970	3.01	.0005738	.06312	....	....	....
74507	.01869	493	9.2130	3.02	.0005644	.27823	....	....	....
81405	.01862	240	4.5737	2.62	.0004879	.11710	....	....	....
81505	.01940	146	2.8327	2.94	.0005704	.08328	2.65	.0005141	.07507
84905	.01927	37	.7130	2.32	.0004471	.01654	....	....	....
84906	.01975	382	7.5438	3.43	.0006773	.25873	....	....	....
88905	.01811	293	5.3069	2.83	.0005126	.15019	....	....	....
88906	.01814	546	9.9034	2.65	.0004807	.26245	....	....	....
92208	.01876	353	6.6205	2.72	.0005102	.18008	....	....	....
92408	.01827	207	3.7820	2.97	.0005426	.11233	....	....	....
92409	.01814	315	5.7131	2.30	.0004171	.13140	....	....	....
92507	.01916	505	9.6779	2.58	.0004944	.24969	....	....	....
92909	.01916	529	10.1363	2.70	.0005173	.27367	....	....	....
94205	.01893	64	1.2117	1.65	.0003124	.01999	....	....	....
94206	.01866	402	7.5005	2.78	.0005187	.20851	....	....	....
94207	.01909	718	13.7057	2.86	.0005460	.39199	....	....	....
94209	.01895	190	3.6006	2.49	.0004719	.08965	....	....	....
94406	.01923	549	10.5556	2.47	.0004749	.26073	....	....	....
94906	.01808	685	12.3862	3.41	.0006166	.42236	....	....	....
94907	.01948	626	12.1918	2.94	.0005726	.35844	....	....	....
94908	.01894	125	2.3678	1.96	.0003713	.04641	....	....	....
95506	.01852	597	11.0548	2.74	.0005074	.30291	....	....	....
95508	.01954	740	14.4617	2.56	.0005003	.37023	....	....	....
95706	.01934	267	5.1629	2.73	.0005279	.14095	....	....	....
Average	.01901	349.6	6.6327	2.88	.0005476	.18039	2.08	.0003979	.15541

WEIGHT OF AVERAGE KERNEL, 0.020 TO 0.022 GRAM.

17308	0.02012	61	1.2275	3.25	0.0006540	0.03994	....	....	....
17405	.02127	738	15.6996	2.13	.0004531	.33441	....	....	....
20705	.02033	163	3.3138	2.78	.0005652	.09212	2.05	0.0004168	0.06793
20708	.02024	122	2.4690	2.58	.0005221	.06399	....	....	....
20709	.02033	258	5.3229	3.05	.0006292	.16235	2.31	.0004766	.12296
20805	.02157	681	14.6942	3.32	.0007161	.48784	2.26	.0004875	.33208

TABLE 10.—*Analyses of plants, arranged according to weight of average kernel. Crop of 1903*—Continued.

WEIGHT OF AVERAGE KERNEL, 0.020 TO 0.022 GRAM—Continued.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—		Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in—	
					Average kernel.	Kernels on plant.		Average kernel.	Kernels on plant.
21212	0.02049	84	1.7216	2.16	0.0004427	0.03718			
21305	.02004	312	6.2514	2.67	.0005350	.16691	1.97	0.0003948	0.12315
21707	.02125	582	12.3685	2.19	.0004654	.27086			
21709	.02141	361	7.7296	2.47	.0005289	.19092			
21811	.02101	567	11.9114	3.75	.0007877	.44666	2.16	.0004538	.25728
21908	.02056	173	3.5574	3.82	.0007855	.13589	1.88	.0003955	.06688
21913	.02072	492	10.1925	3.01	.0006235	.30680			
22210	.02019	298	6.0173	3.17	.0006401	.19075	1.55	.0003129	.09327
22211	.02062	561	11.5675	3.17	.0006537	.36671	1.69	.0003485	.19548
25205	.02066	522	10.7836	2.71	.0005599	.28560			
26908	.02073	192	3.9797	2.96	.0006135	.11780	2.16	.0004478	.08596
27207	.02004	166	3.3266	2.92	.0005850	.09712	1.95	.0003908	.06487
27305	.02085	267	5.5666	2.58	.0005379	.14362	1.73	.0003607	.09630
27505	.02183	539	12.0399	2.12	.0004627	.24942	1.65	.0003602	.19866
28806	.02111	685	14.4630	3.02	.0006376	.43679	1.86	.0003926	.26901
32206	.02052	507	10.4036	1.81	.0003714	.18831			
32605	.02145	94	2.0162	2.88	.0006177	.05807			
33305	.02090	150	3.1346	3.41	.0007126	.10689	2.41	.0005037	.07554
33605	.02144	382	8.1890	2.21	.0004738	.18098			
33607	.02125	136	2.8903	3.22	.0006843	.09307	2.45	.0005206	.07081
33905	.02194	508	11.1476	1.61	.0003533	.17948			
37705	.02155	56	1.2069	2.34	.0005053	.02824			
38606	.02110	401	8.4605	2.63	.0005549	.22251	1.39	.0002933	.11760
39205	.02089	1,031	21.5399	2.11	.0004407	.45435	1.84	.0003844	.39635
39405	.02093	447	9.3541	2.88	.0006027	.21399	1.44	.0003014	.13470
40305	.02011	179	3.6003	3.11	.0006255	.11197			
44605	.02049	55	1.1271	2.86	.0005861	.03223			
44606	.02035	124	2.5235	2.90	.0005902	.07318	1.29	.0002625	.03255
48409	.02048	314	6.4302	2.02	.0004137	.12989	1.50	.0003072	.09645
55005	.02028	393	7.9684	3.05	.0006185	.24303	1.99	.0004036	.15857
55506	.02062	866	17.8506	2.80	.0005773	.4995	2.20	.0004536	.39272
55605	.02184	500	10.9180	2.64	.0005765	.28823	1.96	.0004281	.21400
55908	.02175	562	12.2210	2.42	.0005262	.29575	1.96	.0004263	.23953
57405	.02031	41	.8328	1.98	.0004022	.01649			
57408	.02047	596	12.2004	2.61	.0005343	.31842	1.64	.0003357	.20008
58806	.02049	95	1.9469	1.88	.0003853	.03660			
63106	.02001	165	3.3006	2.79	.0005581	.09208	2.20	.0004402	.07264
65308	.02008	583	11.7066	2.09	.0004197	.24468	1.95	.0003916	.22828
66005	.02073	370	7.6690	2.63	.0005451	.20170	2.18	.0004519	.16714
69506	.02047	663	13.5696	2.50	.0005117	.33923			
69806	.02153	558	12.0136	1.66	.0003574	.19943			
72705	.02191	372	9.1522	2.13	.0004668	.19936			
72707	.02036	225	4.5806	3.49	.0007105	.15986			
73306	.02062	414	8.5373	2.45	.0005052	.20918			
74305	.02047	216	4.4222	1.98	.0004054	.08756			
74606	.02079	464	9.6451	2.30	.0004781	.22184	2.05	.0004262	.19772
80305	.02165	729	15.7835	1.81	.0003919	.28569	1.77	.0003832	.27937
81705	.02106	465	9.7922	1.98	.0004170	.19388	1.96	.0004128	.19193
81706	.02132	722	15.3928	2.71	.0005778	.41715	2.03	.0004328	.31248
81709	.02175	757	16.4692	2.28	.0004960	.37548			
84405	.02043	428	8.7448	2.48	.0005067	.21687			
88606	.02068	481	9.9456	2.53	.0005231	.25162			
88608	.02075	74	1.5355	2.47	.0005125	.03793			
88609	.02100	470	9.8719	2.42	.0005082	.23890			
92406	.02168	380	8.2366	3.11	.0006741	.25616			
92907	.02040	219	4.4673	2.56	.0005220	.11436			
95507	.02029	571	12.1592	2.59	.0005515	.31492			
95509	.02136	138	2.9475	2.48	.0005297	.07310			
Average	.02085	386.6	8.1267	2.60	.0005422	.20510	1.92	.0003999	.17351

WEIGHT OF AVERAGE KERNEL, 0.022 TO 0.024 GRAM.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in average kernel.	Proteid nitrogen (gram) in kernels on plant.	Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in average kernel.	Gliadin-plus-glutenin nitrogen (gram) in kernels on plant.
17307	0.02279	138	3.1454	3.46	0.0007886	0.10883			
17410	.02285	744	16.9987	2.88	.0006580	.48957			
20707	.02282	444	9.9070	2.77	.0006181	.27443	1.85	0.0004222	0.18328
21706	.02390	807	19.3318	4.71	.0011283	.91052			
21708	.02381	390	9.2850	2.33	.0005547	.21634			
21806	.02378	599	14.2450	2.71	.0006444	.38604			
21909	.02317	525	12.1819	4.43	.0010265	.53889	1.98	.0005677	.29846
21911	.02209	383	8.4593	5.48	.0012103	.46356			

TABLE 10.—*Analyses of plants, arranged according to weight of average kernel. Crop of 1903*—Continued.

Record number.	Weight of average kernel (gram).	Number of kernels on plant.	Weight of kernels on plant (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—		Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in—	
					Average kernel.	Kernels on plant.		Average kernel.	Kernels on plant.
WEIGHT OF AVERAGE KERNEL, 0.022 TO 0.024 GRAM—Continued.									
25206	0.02281	205	4.6754	2.76	0.0006295	0.12904			
26106	.02304	90	2.0737	2.63	.0006060	.05454			
26805	.02248	220	4.9456	2.81	.0006317	.13897			
26807	.02390	721	17.2324	2.80	.0006692	.48250			
27506	.02252	444	10.0005	2.70	.0006082	.27003	1.98	0.0004459	0.19800
27508	.02287	251	5.5324	2.64	.0006037	.14608	2.32	.0005306	.12835
27509	.02206	243	5.3615	2.90	.0006399	.15549	1.69	.0002405	.05844
32605	.02323	225	5.2268	1.20	.0002788	.06272			
33407	.02271	305	7.0889	1.62	.0003679	.11223			
33605	.02345	301	7.0596	2.39	.0005605	.16872	1.92	.0004502	.13554
34207	.02219	611	13.5556	2.84	.0006273	.38505			
34606	.02213	280	6.1962	3.12	.0006904	.19332			
38505	.02252	563	12.1088	3.61	.0007764	.43713	1.77	.0003986	.21432
38609	.02309	293	6.7665	2.74	.0006475	.18540	1.34	.0003094	.09067
42405	.02251	66	1.4892	3.07	.0006927	.04572			
43405	.02258	124	2.8000	2.92	.0006594	.08176	1.18	.0002664	.03304
48507	.02296	70	1.6036	2.64	.0006062	.04233			
55308	.02395	397	9.5078	2.54	.0006225	.24150			
55606	.02205	503	11.0930	2.58	.0005690	.28580	1.49	.0002609	.16529
56207	.02361	462	10.9073	2.34	.0005524	.25522	1.83	.0004321	.19960
56208	.02356	563	13.5720	2.61	.0006149	.34616	1.95	.0004594	.26465
57606	.02333	132	3.0790	2.74	.0006391	.08435			
57607	.02234	736	16.4433	1.73	.0003865	.24847			
63107	.02233	417	9.3120	2.43	.0005426	.22628			
65305	.02310	78	1.8018	4.92	.0011365	.08865			
69805	.02220	110	2.4420	5.82	.0012921	.14213	1.94	.0004307	.04738
71905	.02239	1,260	28.2136	2.47	.0005531	.69688			
72708	.02270	398	9.0386	2.27	.0005154	.20518			
73307	.02229	25	.5572	2.39	.0005327	.01332			
73308	.02291	624	14.2986	2.92	.0006539	.41752			
81707	.02336	786	18.3614	2.34	.0005466	.42965			
81710	.02308	396	9.1411	1.92	.0004432	.17550			
88607	.02205	234	5.1584	2.61	.0005754	.13463			
91305	.02242	138	3.0940	3.21	.0007197	.09932			
Average	.02285	388.1	8.8879	2.90	.0006624	.25166	1.74	.0004011	.15515
WEIGHT OF AVERAGE KERNEL, 0.024 TO 0.026 GRAM.									
17506	0.02460	93	2.2881	3.52	0.0008660	0.08044	2.23	0.0005486	0.05102
21807	.02498	377	9.4172	2.73	.0006664	.25709	2.11	.0005271	.19870
21906	.02563	408	10.4800	3.18	.0008168	.33403	2.10	.0005382	.22008
27206	.02469	777	19.1854	2.36	.0005827	.45276	1.46	.0003605	.28010
28805	.02512	87	2.1851	2.91	.0007309	.06359	1.55	.0003894	.03387
37905	.02555	37	.9452	2.53	.0006463	.02391			
40505	.02444	170	4.1546	2.82	.0006892	.11716	2.19	.0005352	.09099
48305	.02543	473	12.0278	2.87	.0007299	.34524	1.77	.0004501	.21289
55907	.02590	749	19.3966	2.59	.0006707	.50238	1.61	.0004170	.31229
72706	.02484	591	14.6802	3.86	.0009588	.56666			
81708	.02578	287	7.3993	2.41	.0006213	.17833	1.64	.0004228	.12135
92206	.02407	46	1.1074	2.67	.0006428	.02957			
94105	.02543	22	.5595	2.67	.0006790	.01494			
Average	.02511	316.7	7.9866	2.86	.0007154	.22816	1.85	.0004654	.16903
WEIGHT OF AVERAGE KERNEL, 0.026 GRAM AND OVER.									
21211	0.02806	10	0.2806	3.15	0.0008839	0.00884			
21705	.02659	58	1.5420	2.45	.0006514	.03778			
39506	.02869	67	1.9218	2.93	.0008404	.05631	2.06	0.0005915	0.03959
49905	.02939	23	.6760	3.62	.0010640	.02436			
55608	.02699	837	22.5848	2.31	.0006236	.52194			
55909	.03050	302	9.2120	2.30	.0007016	.21187	1.66	.0005063	.15292
57508	.03177	380	12.0728	2.21	.0007021	.26680	2.05	.0006513	.24750
58505	.02730	273	7.4516	2.95	.0008052	.21982			
72405	.03963	213	8.4415	3.36	.0013316	.28363			
Average	.02988	240.3	7.2425	2.81	.0008149	.18126	1.92	.0005829	.14667

TABLE 11.—*Summary of analyses of plants, arranged according to weight of average kernel. Crop of 1903.*

Range of weights of average kernel (gram).	Number of analyses.	Weight of average kernel (gram).	Number of kernels.	Weight of kernels (grams).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in—		Percentage of gliadin-plus-glutenin nitrogen in kernels.	Gliadin-plus-glutenin nitrogen (gram) in—	
						Average kernel.	Kernels.		Average kernel.	Kernels.
0 000 to 0.010....	4	0.00915	219	2.0334	2.76	0.0002528	0.05618	1.97	0.0001877	0.05312
0.010 to 0.012....	6	.01118	179	2.0187	2.98	.0003326	.06276	2.69	.0002968	.06752
0 012 to 0.014....	19	.01323	155.7	2.0510	3.12	.0004120	.06687	1.98	.0002641	.07499
0 014 to 0.016....	27	.01516	232	3.5480	3.00	.0004555	.10619	1.76	.0002805	.09320
0 016 to 0.018....	69	.01709	305.9	5.2055	2.93	.0005020	.14618	2.07	.0003519	.13548
0 018 to 0.020....	103	.01901	349.6	6.6327	2.88	.0005476	.18039	2.08	.0003979	.15541
0 020 to 0.022....	64	.02085	386.6	8.1257	2.60	.0005422	.20510	1.92	.0003999	.17351
0 022 to 0.024....	42	.02285	388.1	8.8879	2.90	.0006624	.25166	1.74	.0004011	.15515
0 024 to 0.026	13	.02511	316.7	7.9866	2.86	.0007154	.22816	1.85	.0004654	.16903
0.026 and over..	9	.02988	240.3	7.2425	2.81	.0008449	.18126	1.92	.0005829	.14667

With an increase in the weight of the kernel, as shown by this table, there is an irregular increase in the number of kernels on the plant up to a point somewhat beyond the kernel of average weight, after which there is a decrease. The weight of the kernels on the plant seems to follow the same rule. The percentage of proteid nitrogen in the kernels decreases, in general, with the weight of the average kernel, while the number of grams of proteid nitrogen in the average kernel increases steadily. The grams of proteid nitrogen in all the kernels on the plant increase up to the same point as do the number of kernels on the plant, and then decrease.

Table 12 shows the summary of the analyses of the crop of 1903, arranged according to the grams of proteid nitrogen in the average kernel. All plants having less than 0.0003 gram of proteid nitrogen form the first class, and the following classes increase with each 0.0001 gram of proteid nitrogen.

It is difficult to trace any relation between the grams of proteid nitrogen in the average kernel and the number of kernels on the plant, or the weight of the kernels on the plant. The weight of the average kernel increases directly with the grams of proteid nitrogen in the kernel. The percentage of proteid nitrogen increases regularly with an increase in the grams of proteid nitrogen in the average kernel. The grams of proteid nitrogen in all the kernels on the plant show no definite relation to the grams of proteid nitrogen in the average kernel.

It becomes evident from these results that selection of large, heavy kernels for seed would result in discarding the immature and unsound kernels, but that there would also be discarded many sound kernels, which, although small and of low specific gravity, would contain a high percentage of proteids.

Another effect of such selection, as indicated by the foregoing results, would be to increase the yield of grain from each plant when grown under the conditions that obtained in these experiments. What the effect would be upon the yield under ordinary field conditions these experiments do not indicate.

On the other hand, selection based upon percentage of proteid nitrogen alone would not result in securing plants of greatest yield when raised under these conditions. It would, moreover, not result in obtaining plants producing the greatest amount of proteid nitrogen, nor even of kernels containing the largest quantity of proteid nitrogen.

TABLE 12.—*Summary of analyses of plants, arranged according to grams of proteid nitrogen in average kernel. Crop of 1903.*

Range of proteid nitrogen in average kernel (gram).	Proteid nitrogen in average kernel (gram).	Number of analyses.	Number of kernels on plant.	Weight (in grams) of—		Percentage of proteid nitrogen in kernels.	Proteid nitrogen in kernels on plant (gram).
				Kernels on plant.	Average kernel.		
Below 0.00030	0.0002509	14	257.9	3.9190	0.01364	1.96	0.06531
0.00030 to 0.00040	.0003602	42	266.7	4.6742	.01628	2.31	.09644
0.00940 to 0.00050	.0004537	80	409.2	7.5309	.01811	2.54	.18644
0.00050 to 0.00060	.0005406	116	341.5	6.7159	.01908	2.86	.18440
0.00060 to 0.00070	.0006409	59	310.3	6.7257	.02137	3.07	.19805
0.00070 to 0.00080	.0007430	24	204.9	4.5158	.02110	3.66	.15318
0.00080 to 0.00090	.0008538	9	189.1	4.2480	.02334	3.79	.15944
0.00090 to 0.00100	.0009588	1	591.0	14.6802	.02484	3.86	.56666
0.00100 and over	.0011578	11	244.9	6.6082	.02875	4.62	.27980

It will be shown later that the determination of gliadin-plus-glutenin nitrogen is a safer guide to the bread-making value of wheat than is a determination of proteid nitrogen, but whether selection should be based upon the percentage of nitrogen or the total production of nitrogen by the plant, or upon the amount contained in the average kernel, is a question that can not be solved except by trial under field conditions.

Some results of experiments with light and with heavy seed conducted on large field plots for several years may throw some light on this subject, and are given herewith.

YIELD OF NITROGEN PER ACRE.

It is important to know whether the absolute amount of nitrogen per acre of grain raised is greater in light or in heavy wheat.

If the absolute amount of nitrogen per acre is less in light than in heavy wheat the supposition would be justifiable that the kernels were immature or had been prematurely checked in their development. On the other hand, if the amount of nitrogen per acre is greater in the light wheat it would be reasonable to suppose that, as both had been raised under the same conditions, the light wheat had, in part at least, come from plants that possessed greater ability to acquire and elaborate nitrogenous material.

To afford information on this point analyses were made of crops grown from light and from heavy seed. Records of the yields of the plots were kept in each case so that the actual amount of proteid nitrogen contained in an acre of each kind of wheat can be calculated. The number of grams of proteid nitrogen in 1,000 kernels of each seed and crop sample is also stated. The first samples separated, Nos. 78 and 79 of the Turkish Red variety and 80 and 81 of the Big Frame variety, were taken from seed that had never before been treated in this way. When planted they produced the crops indicated in Table 13 by 78b, 79b, 80b, and 81b, respectively. Each of these crops was then separated into two portions, of which the light portion of the light wheat was retained for analyzing and planting, and the heavy portion of the heavy wheat likewise retained. Thus No. 383 is the light portion of No. 78b, and No. 384 is the heavy portion of No. 79b.

The accuracy of the records of relative yields of light and heavy seed harvested in 1902 being open to suspicion, samples of the same seed were sown again in the autumn of 1902 and harvested in 1903. The results from this test are stated at the bottom of the table under the heading "Check experiment."

These experiments are to be understood as duplicating those of 1902, which, as regards the relative yield of light and heavy wheat, should be accurate, although tried in 1903. The difference between this check experiment and the regular one of 1903 is that in the check experiment the seed of the crop of 1901 was used, while in the regular experiment in 1903 the seed of the crop of 1902 was used.

TABLE 13.—*Crops grown from light and from heavy seed for four years.*

SEED.

Farm number.	Variety.	Percentage of—			Weight of 1,000 kernels. (grams).	Proteid nitrogen in 1,000 kernels (gram).	Relative weight.
		Total nitrogen.	Proteid nitrogen.	Non-proteid nitrogen.			
78	Turkish Red				17.24		Light.
79	.....do				30.63		Heavy.
80	Big Frame	2.45	2.00	0.45	15.57	0.3120	Light
81	.....do	2.20	1.96	.24	28.56	.5606	Heavy.
383	Turkish Red	3.12	3.10	.02	27.11	.8401	Light
384	.....do	3.02	2.93	.09	28.47	.8350	Heavy.
385	Big Frame	3.13	2.82	.31	27.11	.7642	Light
386	.....do	2.95	2.65	.30	28.09	.7446	Heavy
	Turkish Red						Light
	.....do						Heavy
	Big Frame						Light
	.....do						Heavy
957	Turkish Red	3.33	2.87	.46			Light
956	.....do	3.06	2.86	.20			Heavy
952	Big Frame	2.88	2.63	.25			Light
953	.....do						Heavy
	CHECK EXPERIMENT						
	Turkish Red						Light
	.....do						Heavy
	Big Frame						Light
	.....do						Heavy

TABLE 13.—*Crops grown from light and from heavy seed for four years*—Continued.

CROP.

Farm number of seed.	Variety.	Yield per acre (bushels).	Weight per bushel (pounds).	Percentage of—			Proteid nitrogen per acre (pounds).	Weight of 1,000 kernels (grams).	Proteid nitrogen in 1,000 kernels (gram).	Year grown.	Farm number of crop.
				Total nitrogen.	Proteid nitrogen.	Nonproteid nitrogen.					
78	Turkish Red	23.0	......	3.20	3.09	0.11	45.54	......	....	1900	78b
79	do	29.5	......	3.08	2.94	.14	52.04	25.10	0.7379	1900	79b
80	Big Frame	20.5	......	3.13	3.06	.07	37.63	......	....	1900	80b
81	do	25.1	......	2.81	2.59	.22	39.01	24.84	.6423	1900	81b
383	Turkish Red	26.7	60.5	2.35	2.13	.22	34.12	26.19	.5581	1901	612
384	do	29.3	61.5	2.11	1.94	.17	34.11	27.04	.5238	1901	613
385	Big Frame	21.2	58.0	3.30	3.06	.24	38.92	23.89	.7409	1901	602
386	do	27.7	60.5	2.46	2.24	.22	37.22	28.82	.6451	1901	603
	Turkish Red	19.7	57.0	2.15	2.14	.01	25.29	......	....	1902	621
	do	18.0	58.0	1.98	1.87	.11	20.20	......	....	1902	614
	Big Frame	Lost.	......	3.54	3.32	.22	......	19.56	.6494	1902	604
	do	Lost.	......	2.44	2.21	.23	......	26.41	.5837	1902	611
957	Turkish Red	25.6	......	....	3.51	....	53.91	22.12	.7764	1903	1240
956	do	21.3	......	....	2.18	....	27.86	23.13	.5042	1903	1239
952	Big Frame	25.8	......	....	2.14	....	33.13	19.82	.4241	1903	1248
953	do	20.8	......	....	1.98	....	24.71	23.26	.4605	1903	1249
	CHECK EXPERIMENT.										
	Turkish Red	30.9	......	....	1.95	....	36.34	......	....	1903	1245
	do	31.8	......	....	1.64	....	31.29	......	....	1903	1243
	Big Frame	23.9	......	....	1.79	....	25.67	......	....	1903	1252
	do	24.2	......	....	1.62	....	23.52	......	....	1903	1254

Comparing the analyses of the light and heavy seed in this table with those in the preceding tables, it will be noticed that the total and proteid nitrogen are both uniformly higher in the light seed. The nonproteid nitrogen is not so uniform as in the previous analyses, but the general tendency is the same.

In the crop the high total and proteid nitrogen of the light seed is uniformly transmitted. There is no uniformity in the nonproteid nitrogen. As was to be expected, the heavy seed produced in the first two years the largest yields per acre. The quality of light or heavy weight as indicated in the resulting crop by weight of grain per bushel gave some indication of being transmitted. In 1900 there was an absence of data on the subject, but in 1901 the heavy seed in each case produced grain having a greater weight per bushel than did the light seed.

Turning to the column showing the absolute amount of proteid nitrogen produced per acre, it is very apparent that the heavy seed produced in 1900 considerably larger amounts of proteid nitrogen per acre than did the light seed, but in 1901 the difference was very slightly in favor of the light wheat, which advantage continued with the light wheat during the remaining years.

It would seem from these results that the quality of lightness, with its correlated qualities of high total and proteid nitrogen, is hereditary. The question then arises, Why should the light wheat accumulate more nitrogen per acre than the heavy wheat after the first generation?

A possible explanation for this is that the light seed from the first generation contained kernels whose lightness was due in some cases to immaturity, and in other cases to the individual peculiarity of the plant on which they grew. The latter class transmitted this peculiarity in the crop, while the former became less conspicuous with each generation, on account of the lesser vitality and productiveness of the immature seed.

A peculiar feature of these results is found in the fact that the yield of grain from the light seed approaches each succeeding year more nearly in quantity to that obtained from the heavy seed until, in 1903, it becomes greater. These two qualities of seed were raised on plots side by side, and every precaution was taken to obtain an accurate estimate of the yield of each. While it is probable that the results for 1903 are misleading, it is certainly significant that so little difference in yield exists after three years' selection in this way. Instead of the difference between the light and heavy seed becoming greater each year it is without doubt becoming less.

In considering the relative yields of the light and heavy wheat, it must be borne in mind that the seeding was done with a drill set to deliver 1½ bushels per acre of ordinary seed wheat. The result would be to deposit a larger number of kernels of light seed per acre than of heavy seed. In a season like that of 1903, when the rainfall was large and the weather moderately cool until harvest, there might be an advantage resulting from the thicker seeding, which may account for the greater yield from the light seed in that year.

It is possible that the same cause may have operated in other years to increase the yields from the light seed, but it is not likely that it produced a very marked effect, because the seeding was a large one for Nebraska, and, the wheat being sown in the early fall, there was abundant opportunity for it to stool, and thus equalize the stand. It has never been observed that there was any difference between the plots in this respect.

Taking, together, the results of 1902, which show a decrease in the weight of the kernels on a single head as the content of proteid nitrogen increases, the results of 1903, which show a slight decrease in the weight of the kernels from the plant, accompanying an increase in the percentage of proteid nitrogen, and the yields of the light and heavy seed for the four years beginning with 1900, there would appear to be a slight decrease in yield of grain, accompanying an increase in the percentage of proteid nitrogen. This loss in yield is not sufficient to counteract the increase in nitrogen, and the result is to increase the production of proteids per acre.

Viewed in the light of these various experiments, the selection of large, heavy wheat kernels for seed does not appear to be altogether unobjectionable, as in this case it resulted in a decreased production of proteids per acre, without a compensating increase in the yield of grain, when continued for a number of years. On the other hand, the selection of the small, light seed is hardly to be recommended. In fact, selection based upon kernel size or weight is not a satisfactory method for permanently improving wheat. The individual plant should be taken as the basis for selection, and very large numbers should be handled. The figures in Table 8 show what great opportunity there is for securing not only kernels of high nitrogen content, but also plants giving at the same time an increased yield of grain and abundant production of proteids. If the average nitrogen content and yield of grain by plants be observed in this table, it will be seen that numerous plants may be selected that have not only a nitrogen content above the average, but also a greater yield of grain. While, therefore, it is probable that improvement in yield of grain can not be effected so rapidly where it is combined with improvement in nitrogen content as if the latter were neglected, yet present yields of wheat in Nebraska can be increased at the same time that the production of proteids is augmented.

METHOD FOR SELECTION TO INCREASE THE QUANTITY OF PROTEIDS IN THE KERNEL.

The following tables show the results of analyses of a total of forty-eight spikes of wheat. In the case of each spike one row of spikelets, for instance, row No. 1, was analyzed, and the other row of spikelets, which would then be row No. 2, was analyzed separately. In the case of the set of spikes forming Table 14 the total organic nitrogen was determined in both lots, and in the set comprised by Table 15 the proteid nitrogen was determined. The last column shows the difference between the nitrogen content of the two rows of kernels.

TABLE 14.—*Analyses of twenty-five spikes of wheat, showing their total organic nitrogen.*

Number of spike.	Percentage of total organic nitrogen.			Number of spike.	Percentage of total organic nitrogen.		
	Row 1.	Row 2.	Difference.		Row 1.	Row 2.	Difference.
1	3.14	3.32	0.18	18	2.83	2.79	0.04
2	2.97	3.15	.18	22	2.78	2.76	.02
3	2.89	2.99	.10	23	2.94	3.03	.09
7	2.99	3.21	.22	24	2.98	2.89	.09
8	2.89	2.82	.07	44	3.00	3.08	.08
9	2.82	2.81	.01	45	2.84	2.67	.17
10	2.50	2.76	.26	46	3.03	2.90	.13
11	3.13	3.11	.02	47	2.65	2.79	.14
12	3.11	3.18	.07	48	2.62	2.84	.22
13	2.76	2.80	.04	49	3.02	3.18	.16
14	2.85	2.79	.06	50	3.02	2.80	.22
15	3.26	3.07	.19				
16	2.94	3.07	.13	Average			.12
17	3.45	3.67	.22				

TABLE 15.—*Analyses of twenty-three spikes of wheat, showing their percentage of proteid nitrogen.*

Number of spike.	Percentage of proteid nitrogen.			Number of spike.	Percentage of proteid nitrogen.		
	Row 1.	Row 2.	Difference.		Row 1.	Row 2.	Difference.
4	2.90	3.12	0.22	34	2.86	3.02	0.16
5	2.97	2.86	.11	35	2.33	2.52	.19
20	2.68	2.79	.11	36	2.88	2.85	.03
21	2.54	2.76	.22	37	2.43	2.45	.02
25	2.42	2.53	.11	38	3.15	3.14	.01
26	2.42	2.50	.08	39	3.46	3.34	.12
27	3.01	2.91	.10	40	2.45	2.59	.14
28	2.35	2.71	.36	41	2.73	2.68	.05
29	2.72	2.75	.03	42	3.42	3.61	.19
30	2.49	2.44	.05	43	2.47	2.57	.07
31	2.92	3.09	.17				
32	2.60	2.48	.12	Average	2.77	2.82	.11
33	3.41	3.37	.04				

It will readily be seen that the analyses of the rows agree very closely, the extreme difference being 0.22 per cent, and the average difference being 0.12 per cent, in the total nitrogen. If, therefore, one row of spikelets were to be used for seed and the other were analyzed, it is quite evident that a very accurate estimate of the nitrogen content of the kernels used for seed would be obtained. In the determination of proteid nitrogen there is an extreme difference of 0.36 per cent in one case, but in the main the differences are small. As will be shown later, the variation in the proteid nitrogen content of individual plants is so great that even this maximum difference would cause no confusion when selecting plants for reproduction.

It is very desirable to have for analysis a larger sample than can be obtained from one spike. It has therefore been attempted to ascertain whether a sample consisting of one-half the whole number of spikes on a plant would afford a fair estimate of the composition of the other kernels on the remainder of the spikes. The plants whose spikes were analyzed were grown in hills 5 inches apart each way, with one seed in each hill. Each plant was harvested separately and the spikes from each placed in a separate envelope. The following table gives the results, lot 1 in each case being composed of the kernels from one-half the number of spikes on a plant, and lot 2 of kernels from the remaining spikes.

Table 16.—*Analyses of twenty-one plants, showing total nitrogen and proteid nitrogen.*

Number of plant.	Percentage of total nitrogen.			Percentage of proteid nitrogen.		
	Lot 1.	Lot 2.	Difference.	Lot 1.	Lot 2.	Difference.
1	2.65	2.91	0.26	2.51	2.69	0.18
2	3.01	3.02	.01	2.77	2.76	.01
3	3.01	2.83	.24	2.69	2.57	.12
4	2.82	3.10	.28	2.63	2.83	.20
5	3.06	2.97	.09	2.92	2.70	.22
6	2.94	2.56	.38	2.51	2.42	.09
7	2.84	3.03	.19	2.66	2.86	.20
9	3.21	3.05	.16	2.83	2.84	.01
10	2.98	2.87	.11	2.59	2.70	.11
11	2.59	2.66	.07	2.34	2.57	.23
12	2.81	2.62	.19	2.59	2.52	.07
13	3.47	3.62	.15	3.04	3.35	.31
14	2.61	2.54	.07	2.44	2.42	.02
15	2.54	2.46	.08	2.25	2.29	.04
16	2.71	2.87	.16	2.25	2.71	.46
17	2.85	3.01	.16	2.73	2.75	.02
18	2.99	3.13	.14	2.85	2.91	.06
19	2.78	2.77	.01	2.61	2.33	.28
20	2.78	2.80	.02	2.60	2.57	.03
21	2.79	2.71	.08	2.51	2.48	.03
Average			.14			.13

The above table shows a maximum difference of 0.38 per cent in the content of total nitrogen of the two lots of spikes from one plant, and of 0.46 per cent in the content of proteid nitrogen. The average difference is only 0.14 per cent and 0.13 per cent, respectively.

These tables give unmistakable evidences that the average composition of a spike of wheat may be judged from the analysis of a row of its spikelets, and that the average composition of all of the spikes of a wheat plant is shown by an analysis of one-half the number. In practice it is better to take as the sample for analysis one row of spikelets from each spike, and the remaining row of spikelets from each spike for planting.

In order to ascertain what variation occurs between the several spikes on a single wheat plant, analyses were made of each spike from a number of plants. On some plants there were more spikes than on others, but every spike on each plant was analyzed. In the following tabulation of these analyses the percentage of proteid nitrogen is stated.

TABLE 17.—*Analyses of spikes of wheat, showing difference in proteid nitrogen.*

Spike.	Percentage of proteid nitrogen.					
	Plant 23.	Plant 24.	Plant 25.	Plant 26.	Plant 27.	Plant 29.
1	2.33	2.46	2.31	2.73	3.22	2.38
2	2.69	2.73	2.36	3.02	3.24	2.60
3	2.37	2.35	2.47	2.80	3.02	3.03
4	2.36	2.11	2.59	2.60	3.31	3.00
5	2.15	2.19	2.35	2.53	....	2.34
6	2.31	2.21	2.39	2.37	....	2.71
7	2.09	2.53	2.39	2.72	....	2.21
8	2.71	....	2.60	2.37	....	....
9	2.32	....	2.54	2.61	....	2.60
10	2.37	....	2.83	2.45	....	2.30
Maximum	2.69	2.73	2.83	3.02	3.31	3.03
Average	2.37	2.37	2.48	2.62	3.20	2.57
Minimum	2.09	2.11	2.31	2.37	3.02	2.21
Greatest difference	.60	.62	.52	.65	.29	.82

These results show that there may be large differences between the proteid nitrogen content of spikes on the same plant. They do not, however, indicate that the determination of the average composition of the kernels on a plant is not a safe guide for selecting breeding stock. If the plant is the unit in reproduction, whether the plant reproduces itself from one seed or another does not affect its hereditary qualities in very marked degree.

It is evident, from a comparison of the variations that occur in the composition of the spikes from a single plant, and of the kernels on a single spike, that it is impossible to do more than obtain a reasonably close estimate of the composition of the kernels either on a part or on the whole of a plant. It therefore becomes desirable to obtain as closely as possible the average composition of the unit of reproduction. If the plant as a whole, and not any particular part, is this unit, the average composition of all of the kernels on the plant is a much safer guide as a basis for selection than is the average composition of the kernels of any part of it. One row of spikelets from each spike should therefore give the best sample for analysis.

In Table 18 is given a statement of the percentage of proteid nitrogen in the dry matter of the kernels on a row of spikelets of 800 spikes of wheat of the Turkish Red variety. These spikes were taken from a field of wheat, and were selected with reference to length of head, plumpness of kernel, uprightness of straw, freedom from rust, etc. They are therefore not spikes in which high nitrogen content is likely to be due to immaturity or arrested development.[a] Variations in the nitrogen content of different plants may in some degree be due to a larger or smaller supply of available nitrogen, although all were taken from the same field. Variations due to climate are, of course, precluded, as all grew during the same season.

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[a] In practice undeveloped kernels are discarded.

TABLE 18.—*Variations in content of proteids.*

Record number	Percentage of—		Record number.	Percentage of—		Record number.	Percentage of—	
	Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).		Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).		Proteid nitrogen in water-free material	Proteids (proteid N. × 5.7).
1	2.25	12.82	78	3.40	19.38	155	1.99	11.37
2	3.04	17.33	79	3.33	18.98	156	3.03	17.20
3	2.45	13.96	80	3.79	21.60	157	2.07	11.87
4	3.14	17.90	81	3.63	20.69	158	2.75	15.64
5	2.86	16.30	82	2.68	15.28	159	2.82	16.07
6	2.83	16.13	83			160	3.06	17.44
7	3.67	20.92	84	2.46	14.02	161	2.54	14.48
8	3.42	19.49	85	2.62	14.93	162	3.33	18.98
9	2.36	13.45	86	2.87	16.49	163	2.73	15.56
10	2.28	13.00	87	2.89	16.86	164	2.47	14.08
11	2.98	16.99	88	2.44	13.91	165	3.22	18.35
12	3.51	20.01	89	3.56	20.29	166	2.80	15.96
13	3.63	20.69	90	3.76	21.43	167		
14	2.48	14.14	91			168	3.59	20.46
15	2.30	13.11	92	3.41	19.44	169	2.52	13.72
16	3.48	19.84	93	2.30	13.11	170	2.72	15.50
17	3.55	20.23	94			171	3.28	18.70
18	3.31	18.87	95			172	2.74	15.62
19	2.30	13.11	96	2.75	15.67	173	3.07	17.54
20	2.52	14.36	97	4.07	23.20	174	3.75	21.43
21	2.93	16.70	98	3.28	18.70	175	3.46	19.74
22	3.25	18.52	99	3.24	18.47	176	3.09	17.67
23			100	2.15	12.25	177	3.56	20.34
24	2.84	16.19	101	3.12	17.78	178		
25	2.73	15.56	102	3.00	17.10	179	3.85	21.95
26	3.55	20.23	103	2.87	16.36	180	3.57	20.38
27	2.33	13.28	104	3.58	20.41	181	2.66	15.18
28	2.65	15.11	105	2.61	14.88	182	2.76	15.74
29	2.82	16.07	106	2.01	11.46	183	2.05	11.73
30	2.70	15.39	107	2.68	15.28	184	3.77	21.53
31	1.84	10.49	108	3.10	17.67	185	2.70	15.43
32	3.10	17.67	109	2.58	14.71	186	3.97	22.63
33	2.86	16.30	110	2.76	15.73	187	2.98	17.03
34	2.16	12.31	111	4.30	24.51	188	2.36	13.48
35	2.58	14.71	112	2.89	16.47	189	2.63	15.03
36	3.22	18.35	113	2.59	14.67	190	3.24	18.52
37	3.49	19.89	114	2.68	15.28	191	3.24	18.52
38	2.76	15.73	115	1.71	9.75	192	3.12	17.80
39	2.96	16.87	116	2.59	14.75	193	2.40	13.72
40	2.86	16.30	117	3.31	18.87	194	3.43	19.58
41	3.50	19.95	118			195	3.33	18.99
42	3.05	17.38	119	2.17	12.37	196	2.71	15.46
43	2.88	16.42	120	2.88	16.42	197	2.85	16.27
44	2.75	15.67	121			198	3.18	18.13
45	2.61	14.88	122	1.33	7.58	199	2.98	17.03
46	2.50	14.25	123	2.54	14.48	200	3.23	18.46
47	3.10	17.67	124	3.20	18.24	201		
48	3.17	18.07	125	2.04	11.63	202	3.12	17.83
49	2.86	16.30	126	2.34	13.34	203	3.07	17.51
50	2.80	15.96	127	2.89	16.47	204	3.90	22.24
51	3.65	20.80	128	2.98	16.99	205	2.41	13.74
52	2.88	16.42	129	2.85	16.24	206	3.44	19.62
53	3.21	18.30	130	2.99	17.04	207	2.73	15.58
54	2.96	16.87	131	3.18	18.13	208	3.20	18.30
55	3.84	21.89	132			209	3.81	21.76
56	3.38	19.27	133			210	2.94	16.79
57	3.11	17.73	134			211	2.89	16.52
58	3.21	18.30	135			212	2.96	16.91
59	3.06	17.44	136			213	3.30	18.86
60	3.02	17.21	137	2.13	12.14	214	3.09	17.62
61	1.78	10.13	138	3.08	17.56	215	3.79	21.63
62	2.67	15.22	139	1.37	7.81	216	3.33	18.99
63	3.39	19.32	140			217	2.86	16.30
64	2.49	14.19	141	2.57	14.65	218	2.58	14.72
65	2.58	14.71	142	2.75	15.67	219	2.71	15.45
66	2.12	12.08	143	3.03	17.27	220	3.19	18.22
67	2.64	15.05	144	3.17	18.07	221	3.98	22.70
68	2.46	14.02	145	2.09	11.91	222	2.93	16.71
69	2.35	13.39	146	2.75	15.67	223	3.30	18.86
70	2.93	16.70	147	2.42	13.79	224	3.65	20.82
71	2.32	13.22	148	2.68	15.28	225	3.54	20.23
72	2.20	12.54	149	2.25	12.82	226	3.11	17.73
73	2.58	14.71	150	2.61	14.88	227	2.71	15.46
74	2.58	14.71	151	1.51	8.61	228	3.39	19.36
75	3.22	18.35	152	1.64	9.35	229	2.96	16.88
76			153	2.93	16.70	230	2.54	14.46
77			154	2.85	16.24	231	3.11	17.73

TABLE 18.—*Variations in content of proteids*—Continued.

Record number.	Percentage of—		Record number.	Percentage of—		Record number.	Percentage of—	
	Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).		Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).		Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).
232	3.11	17.73	309	3.74	21.36	386	2.52	15.07
233	3.31	18.92	310	3.15	18.01	387	2.73	15.59
234	3.23	18.43	311	2.99	17.07	388	3.05	17.41
235	3.65	20.82	312	3.48	19.88	389	2.95	16.87
236	3.18	18.17	313	3.52	20.11	390	3.22	18.36
237	4.87	27.79	314	3.16	18.03	391	3.26	18.60
238	2.69	15.38	315	2.75	15.68	392	2.93	16.74
239	2.59	14.77	316	3.35	19.13	393	2.70	15.41
240	3.52	20.12	317	3.42	19.54	394	2.77	15.81
241	2.76	15.75	318	2.01	11.50	395	2.98	16.99
242	2.96	16.89	319	2.86	16.33	396	2.28	13.02
243	3.47	19.78	320	2.98	17.00	397	....	....
244	3.30	18.83	321	3.42	19.54	398	....	....
245	3.64	20.77	322	2.54	14.53	399	3.09	17.65
246	3.75	21.39	323	3.42	19.54	400	3.35	19.12
247	3.50	19.95	324	3.18	18.16	401	3.36	19.20
248	3.64	20.78	325	3.45	19.70	402	2.32	13.26
249	3.21	18.32	326	....	....	403	3.03	17.31
250	3.11	17.76	327	3.44	19.64	404	3.30	18.83
251	3.46	19.73	328	3.60	20.55	405	3.75	21.43
252	2.54	14.52	329	2.87	16.39	406	2.43	13.90
253	3.63	20.71	330	2.61	14.93	407	3.79	21.63
254	....	....	331	....	....	408	3.63	20.74
255	3.02	17.26	332	2.57	14.68	409	3.59	20.47
256	3.31	18.88	333	3.25	18.56	410	3.26	18.63
257	....	....	334	2.61	14.92	411	3.15	17.95
258	3.37	19.24	335	2.81	15.70	412	3.63	20.70
259	3.84	21.89	336	3.35	19.11	413	3.77	21.51
260	1.93	11.03	337	2.88	16.45	414	3.13	17.89
261	3.49	19.92	338	4.95	28.23	415	2.44	13.93
262	3.19	18.21	339	3.33	19.01	416	3.23	18.44
263	3.24	18.48	340	2.73	15.61	417	3.79	21.65
264	3.36	19.20	341	2.97	16.94	418	3.05	17.39
265	3.29	18.80	342	2.60	14.82	419	2.85	16.28
266	3.10	17.70	343	2.50	14.27	420	3.73	21.27
267	3.18	18.18	344	2.93	16.71	421	2.53	14.45
268	4.10	23.39	345	2.55	14.57	422	3.53	20.12
269	3.20	18.29	346	2.55	14.55	423	3.14	17.90
270	3.36	19.19	347	2.44	13.92	424	2.61	14.93
271	3.39	19.34	348	2.87	16.39	425	3.29	18.81
272	3.13	17.88	349	2.65	15.18	426	3.08	17.60
273	3.39	19.78	350	2.63	15.03	427	3.06	17.46
274	3.56	20.34	351	3.31	18.90	428	2.59	14.80
275	3.32	18.96	352	3.04	17.38	429	3.03	17.31
276	3.15	17.95	353	3.10	17.72	430	2.81	16.06
277	2.85	16.26	354	2.72	15.53	431	3.20	18.25
278	3.11	17.77	355	2.83	16.18	432	3.00	17.11
279	3.78	21.60	356	2.91	16.61	433	3.12	17.80
280	3.70	21.10	357	2.36	13.47	434	2.85	16.28
281	3.26	18.60	358	2.33	13.60	435	3.53	20.14
282	3.01	17.19	359	2.97	16.95	436	2.88	16.44
283	3.85	22.00	360	2.88	16.45	437	3.12	17.82
284	3.71	21.20	361	2.94	16.77	438	2.66	15.20
285	3.87	22.07	362	3.03	17.28	439	2.98	16.99
286	3.55	20.26	363	3.49	19.89	440	2.35	13.44
287	3.86	22.04	364	2.91	16.62	441	2.93	16.72
288	2.82	16.09	365	3.49	19.94	442	3.22	17.98
289	2.52	14.40	366	3.16	18.04	443	2.50	14.30
290	4.00	22.81	367	3.37	19.23	444	2.37	13.56
291	2.23	12.73	368	3.06	17.47	445	2.37	13.51
292	4.15	23.68	369	3.33	19.02	446	3.75	21.37
293	2.63	15.04	370	3.09	17.64	447	2.86	16.33
294	2.56	14.60	371	2.98	17.04	448	3.13	16.67
295	3.05	17.41	372	3.30	18.84	449	2.76	15.76
296	3.93	22.44	373	2.86	16.33	450	3.61	20.62
297	1.99	11.35	374	3.15	17.97	451	2.92	16.68
298	....	....	375	3.40	19.89	452	3.17	18.07
299	3.67	20.96	376	2.59	14.76	453	3.15	17.96
300	3.06	17.49	377	3.46	19.76	454	3.14	17.92
301	3.08	17.61	378	2.74	15.65	455	2.62	14.95
302	2.68	15.28	379	3.09	17.64	456	2.71	15.47
303	....	....	380	2.35	13.42	457	3.14	17.92
304	2.23	12.71	381	3.45	19.67	458	3.18	18.20
305	3.07	17.52	382	3.22	18.40	459	2.60	14.84
306	2.50	14.30	383	2.96	16.88	460	3.91	22.29
307	3.19	18.20	384	3.55	20.26	461	....	....
308	2.84	16.22	385	3.79	21.62	462	2.39	13.64

TABLE 18.—*Variations in content of proteids*—Continued.

Record number.	Percentage of—		Record number.	Percentage of—		Record number.	Percentage of—	
	Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).		Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).		Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).
463	2.49	14.24	540	3.17	18.12	617	3.12	17.83
464	1.98	11.29	541	3.09	17.66	618	2.67	15.27
465	3.32	18.97	542	3.33	19.01	619	3.59	20.49
466	2.98	17.01	543	3.50	19.96	620	2.68	15.30
467	2.89	16.48	544	1.29	7.37	621	2.24	12.79
468	2.95	16.82	545	2.10	11.98	622	3.19	18.23
469	2.74	15.62	546	2.54	14.49	623	3.52	20.09
470	2.80	15.97	547	2.73	15.59	624	2.67	15.27
471	2.24	12.79	548	3.01	17.21	625	2.68	15.30
472	2.49	14.22	549	2.50	14.30	626	2.69	15.38
473	2.76	15.78	550	2.84	16.20	627	2.88	16.44
474	2.80	15.97	551	2.99	17.08	628	3.68	21.01
475	2.95	16.83	552	2.30	13.11	629	3.47	19.82
476	2.52	14.39	553	3.21	18.35	630	2.48	14.16
477	2.95	16.85	554	2.91	16.59	631	3.39	19.35
478	3.15	18.00	555	3.16	18.06	632	3.22	18.41
479	2.27	12.96	556	3.02	17.26	633	1.64	9.38
480	2.72	15.53	557	3.30	18.86	634	2.10	11.99
481	3.04	17.38	558	3.25	18.58	635	3.42	19.52
482	3.15	17.97	559	2.94	16.78	636	3.08	17.61
483	2.60	14.86	560	3.32	18.93	637	2.77	15.79
484	3.45	19.71	561	3.00	17.13	638	3.54	20.21
485	2.59	14.81	562	1.12	6.40	639	3.15	18.00
486	2.68	15.31	563	2.36	13.49	640	2.82	16.10
487	3.01	17.18	564	3.83	21.84	641	3.37	19.26
488	2.41	13.77	565			642	2.57	14.68
489	3.45	19.70	566	3.49	19.49	643	3.35	19.14
490	2.46	14.02	567	3.08	17.57	644	3.41	19.47
491	2.87	16.40	568	2.17	12.39	645	2.44	13.91
492	2.06	11.78	569	3.03	17.29	646	3.77	21.54
493	3.18	18.16	570	3.20	18.27	647	2.82	16.08
494	2.45	13.97	571	2.52	14.37	648	2.53	14.47
495	2.36	13.45	572	3.12	17.82	649	2.56	14.63
496	2.52	14.38	573	2.52	14.41	650	2.59	14.82
497	2.84	16.21	574	3.25	18.53	651		
498	2.82	16.08	575	3.17	18.10	652	2.83	16.19
499	2.97	16.95	576	2.52	14.40	653	2.50	14.31
500	3.06	17.48	577	3.09	17.61	654	2.59	14.81
501	2.64	15.09	578	2.73	15.60	655	3.21	18.30
502	2.72	15.56	579	3.35	19.10	656	2.56	14.61
503	2.31	13.19	580			657	2.55	14.57
504	3.06	17.48	581	3.79	21.61	658		
505	2.71	15.46	582	2.59	14.77	659	2.92	16.70
506	2.49	14.24	583	3.13	17.86	660	3.26	18.60
507	3.13	17.85	584	3.49	19.91	661	2.55	14.56
508	2.89	16.51	585	3.05	17.40	662	2.50	14.26
509	3.20	18.29	586	3.27	18.65	663	2.82	16.11
510	2.93	16.71	587	2.56	14.60	664	2.80	15.98
511	3.61	20.59	588	2.83	16.17	665	3.33	19.01
512	2.71	15.45	589	2.84	16.20	666	2.35	13.40
513	2.86	16.33	590	2.86	16.31	667	2.31	13.20
514	2.41	13.79	591	3.06	17.44	668	2.50	14.30
515	2.27	12.98	592	3.20	18.29	669	4.36	24.86
516	3.28	18.75	593	2.88	16.47	670	6.33	36.12
517	2.36	13.49	594	3.32	18.93	671	2.32	13.23
518	3.64	20.75	595	3.18	18.17	672	4.82	28.15
519	2.81	16.03	596	3.09	17.66	673	3.39	19.35
520	2.54	14.48	597	3.32	18.93	674	3.24	18.48
521	2.68	15.28	598	2.34	13.39	675	3.41	19.44
522	3.12	17.79	599	3.12	17.81	676	3.11	17.73
523	2.99	17.05	600	2.97	16.97	677	2.51	14.36
524	1.93	11.04	601	2.08	11.91	678	3.09	17.65
525	2.51	14.35	602	3.64	20.77	679	2.48	14.17
526	1.71	9.79	603	2.56	14.62	680	2.30	13.13
527	3.15	17.99	604	2.53	14.45	681	3.36	19.17
528	2.35	13.42	605	2.56	14.60	682	2.49	14.20
529	2.88	16.44	606	3.13	17.85	683	2.70	15.41
530	2.64	15.06	607	3.01	17.20	684	3.59	20.51
531	2.97	16.94	608	3.05	17.41	685	4.04	23.06
532	2.75	15.73	609	2.75	15.72	686	2.79	15.90
533	3.22	18.37	610	3.51	20.05	687	2.83	16.13
534	2.95	16.82	611	3.00	17.15	688	2.65	15.12
535	3.03	17.29	612	3.26	18.62	689	2.68	15.28
536	2.57	14.66	613	3.84	21.92	690	3.38	19.26
537	2.88	16.47	614	2.77	15.79	691	3.04	17.33
538	2.64	15.09	615	2.72	15.52	692	2.81	16.04
539	3.76	21.46	616	3.72	21.22	693	2.35	13.76

TABLE 18.—*Variations in content of proteids*—Continued.

Record number.	Percentage of—		Record number.	Percentage of—		Record number.	Percentage of—	
	Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).		Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).		Proteid nitrogen in water-free material.	Proteids (proteid N. × 5.7).
694	2.15	12.29	730	2.09	11.92	766	2.87	16.41
695	2.92	16.69	731	3.18	18.18	767	2.22	12.69
696	....	....	732	2.41	13.78	768	2.45	13.98
697	2.11	12.07	733	2.06	11.77	769	2.37	13.51
698	3.03	17.29	734	2.76	15.73	770	1.37	7.86
699	2.64	15.09	735	2.09	11.96	771	1.62	9.27
700	4.10	23.42	736	2.29	13.09	772	2.00	11.42
701	2.51	14.33	737	1.61	9.20	773	1.73	9.87
702	2.27	12.96	738	2.01	11.44	774	2.32	13.26
703	2.33	13.34	739	2.85	16.26	775	1.88	10.76
704	2.43	13.94	740	1.87	10.71	776	2.28	13.03
705	2.48	14.18	741	1.75	9.99	777	2.80	16.02
706	1.87	10.69	742	3.57	20.36	778	1.98	11.33
707	3.07	17.52	743	2.63	15.02	779	2.35	13.40
708	2.12	12.09	744	1.97	11.23	780	2.85	16.29
709	1.87	10.67	745	2.98	16.99	781	2.79	15.94
710	2.10	12.00	746	1.77	10.10	782	2.64	15.09
711	2.08	11.87	747	2.79	15.95	783	2.81	16.02
712	2.61	14.88	748	1.83	10.44	784	1.92	10.96
713	2.20	12.58	749	2.29	13.06	785	2.25	12.88
714	2.16	12.32	750	2.22	12.66	786	3.29	18.75
715	3.23	18.44	751	3.48	19.85	787	2.95	16.82
716	2.77	15.81	752	3.48	19.87	788	2.13	12.17
717	2.38	13.61	753	1.33	7.53	789	2.20	12.57
718	3.14	17.91	754	3.55	20.29	790	2.86	16.52
719	2.16	12.35	755	2.43	13.90	791	3.02	17.22
720	1.80	10.29	756	2.30	13.15	792	2.16	12.36
721	2.14	12.22	757	2.14	12.24	793	2.32	13.24
722	2.16	12.36	758	1.67	9.54	794	2.82	16.11
723	2.18	12.43	759	2.14	12.25	795	2.48	14.15
724	2.04	11.67	760	3.72	21.21	796	2.45	14.00
725	2.32	13.26	761	2.47	14.12	797	2.20	12.56
726	2.19	12.52	762	2.93	16.72	798	2.95	16.82
727	1.79	10.23	763	2.02	11.56	799	2.18	12.48
728	2.49	14.22	764	2.18	12.47	800	2.02	11.57
729	2.92	16.46	765	2.20	12.57			

It will be noticed that there is a very large range of variation in the proteid nitrogen content of these wheats, running from 1.12 to 4.95 per cent. By referring to Table 8, it will be seen that an equally large variation occurred between the plants when the whole plant was sampled. In the 351 analyses the nitrogen ranges from 1.20 to 5.85 per cent. This is due in the main to the ability of the plant to gather nitrogen from the soil. In no one of the experiments to ascertain the effect of nitrogenous manures on the composition of wheat has there been an increase of more than a few tenths of 1 per cent, even when the nitrogenous fertilizer was added to an exhausted soil. It is, therefore, not likely that such large variation in nitrogen content could be due to irregularities in the supply of soil nitrogen. If this ability of the plant to store up a large amount of nitrogen in the kernel is hereditary, as results given later indicate, there is ample opportunity to develop by selection a strain of wheat of high nitrogen content.

A BASIS FOR SELECTION TO INCREASE THE QUANTITY OF PROTEIDS IN THE ENDOSPERM OF THE KERNEL.

White bread flour, which constitutes the major portion of the wheat flour consumed in this country, is derived entirely from the endosperm of the wheat kernel. The portions of the kernel not entering into the flour are the germ and the seed coat, attached to each of which discarded constituents are portions of the endosperm. The larger part of the aleurone layer either adheres to the hull and constitutes the "bran" of commerce, or appears in the product known as "shorts," and sometimes in low-grade flour.

As it is the flour in which it is desired to increase the nitrogen, and as the flour consists entirely of the endosperm, it becomes desirable to have some way to determine the nitrogen content of the endosperm alone and to select for reproduction plants possessing a large amount of nitrogen in this portion of the kernel.

It is a question how this can best be done. A determination of gluten by the ordinary method of washing, to carry off the starch and fiber while the gluten is being worked in the hand, is not well adapted for use with the small quantities of wheat obtainable from a single plant. This also has the disadvantage that it gives no indication as to the quality of the gluten.

Determinations of gliadin and glutenin promise to be of some help in affording a basis for selection from individual plants. It has been shown by Osborne and Voorhees[a] that the gluten of wheat is composed of gliadin and glutenin. It does not necessarily follow, however, that the sum of these two substances is a measure of the gluten content of the sample analyzed. Osborne and Campbell[b] have stated that the embryo of the wheat kernel does not contain either gliadin or glutenin. This being the case, the sum of the gliadin and glutenin would represent these proteids in the endosperm, with, perhaps, a small amount in the hull.

A recent investigation by Nasmith[c] leads him to conclude that gliadin exists in all portions of the endosperm, including the aleurone layer, but that glutenin is contained only in the starch-bearing portion of the endosperm. A determination of glutenin may, therefore, give an indication of the gluten content of the wheat.

Table 19 shows the percentage of proteid nitrogen, the sum of the gliadin and glutenin nitrogen, the amounts in grams of proteid and of gliadin-plus-glutenin nitrogen in the average kernel, and the grams of proteid and of gliadin-plus-glutenin nitrogen in all of the kernels on each plant. The plants are grouped into those having from 1 to 2 per cent proteid nitrogen, those having 2 to 2.5 per cent proteid nitrogen, etc. Table 20 gives the averages for each of the groups in Table 19.

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[a] American Chem. Jour., 1893, pp. 392–471.

[b] Connecticut Experiment Station Report, 1899, p. 305.

[c] Trans. Canad. Inst., 7 (1903), Univ. Toronto Studies, Physiol. Ser. (1903), No. 4.

TABLE 19.—*Relation of gliadin-plus-glutenin nitrogen to proteid nitrogen.*

1 TO 2 PER CENT PROTEID NITROGEN.

Record number.	Percentage of— Proteid nitrogen.	Percentage of— Gliadin-plus-glutenin nitrogen.	Number of kernels.	Weight (in grams) of— Kernels.	Weight (in grams) of— Average kernel.	Weight (in grams) of— Proteid nitrogen in kernels.	Weight (in grams) of— Gliadin-plus-glutenin nitrogen in kernels.	Weight (in grams) of— Proteid nitrogen in average kernel.	Weight (in grams) of— Gliadin-plus-glutenin nitrogen in average kernel.
55307	1.89	1.56	342	5.6864	0.01663	0.10747	0.08871	0.0003142	0.0002594
80305	1.81	1.77	729	15.7835	.02165	.28569	.27937	.0003919	.0003832
81705	1.98	1.96	465	9.7922	.02106	.19388	.19193	.0004170	.0004128
Average	1.89	1.76	512	10.4207	.01978	.19568	.18667	.0003744	.0003518
2 TO 2.5 PER CENT PROTEID NITROGEN.									
21212	2.16	0.19	84	1.7216	0.02049	0.03718	0.00327	0.0004427	0.0000389
27205	2.41	1.70	891	16.4061	.01841	.39539	.27890	.0004437	.0003130
27206	2.36	1.46	777	19.1854	.02469	.45276	.28010	.0005827	.0003605
27505	2.12	1.65	539	12.0399	.02183	.24942	.19866	.0004627	.0003602
33107	2.35	2.12	318	6.1026	.01919	.14341	.12643	.0004510	.0004163
33605	2.39	1.92	301	7.0596	.02345	.16872	.13554	.0005605	.0004502
39205	2.11	1.84	1,031	21.5399	.02089	.45435	.39635	.0004407	.0003844
48106	2.38	1.80	608	11.6655	.01919	.27765	.20997	.0004567	.0003454
48409	2.02	1.50	314	6.4302	.02048	.12989	.09645	.0004137	.0003072
55309	2.48	1.97	167	2.5160	.01507	.06240	.04957	.0003736	.0002969
55908	2.42	1.96	562	12.2210	.02175	.29575	.23953	.0005262	.0004263
55909	2.30	1.66	302	9.2120	.03050	.21187	.15292	.0007016	.0005063
56206	2.42	1.95	509	9.3093	.01829	.22529	.18153	.0004426	.0003566
56207	2.34	1.83	462	10.9073	.02361	.25522	.19960	.0005524	.0004321
57508	2.21	2.05	380	12.0728	.03177	.26680	.24750	.0007021	.0006513
65306	2.41	1.68	544	9.8298	.01807	.23690	.16514	.0004355	.0003036
65307	2.28	1.81	373	7.0051	.01878	.15971	.12680	.0004282	.0003399
65308	2.09	1.95	583	11.7066	.02008	.24468	.22828	.0004197	.0003916
74606	2.30	2.05	464	9.6451	.02079	.22184	.19772	.0004781	.0004262
81707	2.34	.64	786	18.3614	.02336	.42965	.11750	.0005466	.0001495
81708	2.41	1.64	287	7.3993	.02578	.17833	.12135	.0006213	.0004228
Average	2.30	1.68	489.6	10.5874	.02173	.24272	.17872	.0004991	.0003652
2.5 TO 3 PER CENT PROTEID NITROGEN.									
20706	2.78	2.05	163	3.3138	0.02033	0.09212	0.06793	0.0005652	0.0004168
20707	2.77	1.85	444	9.9070	.02282	.27443	.18328	.0006181	.0004222
20710	2.83	2.00	867	17.1115	.01974	.48428	.34222	.0005586	.0003948
21207	2.96	.17	118	2.3066	.01955	.06804	.00392	.0005766	.0000332
21305	2.67	1.97	313	6.2514	.02004	.16691	.12315	.0005353	.0003948
21306	2.90	.97	226	4.1516	.01837	.12039	.04027	.0005327	.0001782
21805	2.69	.23	1,232	20.9290	.01699	.56299	.04704	.0004569	.0000391
21807	2.73	2.11	377	9.4172	.02498	.25709	.19870	.0006664	.0005271
21808	2.57	1.96	1,156	19.7446	.01708	.50744	.38700	.0004389	.0003348
21809	2.73	2.18	418	8.0214	.01919	.21898	.17487	.0005238	.0004183
21905	2.64	2.18	791	14.3111	.01809	.37781	.31198	.0004777	.0003944
22205	2.81	1.97	283	2.6965	.00953	.07577	.05312	.0002677	.0001877
22207	2.77	1.82	169	3.2787	.01940	.09082	.05967	.0005374	.0003531
26905	2.76	2.09	326	6.4102	.01966	.17692	.13398	.0005427	.0004109
26906	2.71	1.82	228	4.2376	.01859	.11484	.07712	.0005037	.0003383
26908	2.96	2.16	192	3.9797	.02073	.11780	.08596	.0006135	.0004478
26909	2.80	1.88	180	2.9999	.01667	.08400	.05640	.0004667	.0003134
27005	2.63	1.90	866	16.4120	.01895	.43161	.31182	.0004984	.0003600
27207	2.92	1.95	166	3.3266	.02004	.09712	.06487	.0005850	.0003908
27305	2.58	1.73	267	5.5666	.02085	.14362	.09630	.0005379	.0003607
27307	2.53	.82	167	3.0850	.01847	.07805	.02530	.0004674	.0001515
27506	2.70	1.98	444	10.0035	.02252	.27003	.19800	.0006082	.0004459
27508	2.64	2.32	251	5.5324	.02287	.14608	.12835	.0006037	.0005116
27509	2.90	1.09	243	5.3615	.02206	.15549	.05841	.0006399	.0002405

TABLE 19.—*Relation of gliadin-plus-glutenin nitrogen to proteid nitrogen*—Continued.

2.5 TO 3 PER CENT PROTEID NITROGEN—Continued.

Record number.	Percentage of—		Number of kernels.	Weight (in grams) of—					
	Proteid nitrogen.	Gliadin-plus-glutenin nitrogen.		Kernels.	Average kernel.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in average kernel.
28805	2.91	1.55	87	2.1851	0.02512	0.06359	0.03387	0.0007309	0.0003894
33105	2.91	3.50	132	2.5601	.01939	.07450	.05960	.0005644	.0006787
37305	2.96	2.29	309	6.1391	.01987	.18173	.14060	.0005881	.0004550
37705	2.64	1.26	461	8.0905	.01972	.23998	.10194	.0005327	.0002485
37707	2.93	2.10	193	3.3004	.01710	.09670	.06931	.0005010	.0003591
38005	2.84	1.23	139	2.5134	.01808	.07138	.03091	.0005135	.0002224
38606	2.63	1.39	401	8.4605	.02110	.22251	.11760	.0005549	.0002933
38608	2.82	1.73	158	3.0228	.01913	.08522	.05229	.0005394	.0003309
38609	2.74	1.34	293	6.7665	.02309	.18540	.09067	.0006475	.0003094
39405	2.88	1.44	447	9.3541	.02093	.21399	.13470	.0006027	.0003014
39506	2.93	2.06	67	1.9218	.02869	.05631	.03959	.0008404	.0005910
40505	2.82	2 19	170	4.1546	.02444	.11716	.09099	.0006892	.0005352
43405	2.92	1.18	124	2.8000	.02258	.08176	.03304	.0006594	.0002664
44505	2.94	.70	340	5.9990	.01764	.17637	.04199	.0005187	.0001235
44606	2.90	1.29	124	2.5235	.02035	.07318	.03255	.0005902	.0002625
46107	2.54	2.08	478	8.3935	.01756	.21319	.17458	.0004460	.0003652
48305	2.87	1.77	473	12.0278	.02543	.34524	.21289	.0007299	.0004501
48806	2.70	.75	547	9.8346	.01798	.26553	.07376	.0004877	.0001348
55008	2.60	1.58	944	17.4226	.01846	.45299	.27528	.0004799	.0002917
55206	2.56	1.87	578	11.3592	.01965	.29079	.21241	.0005031	.0003675
55308	2.54	.65	397	9.5078	.02395	.24150	.06180	.0006225	.0001557
55506	2.80	2.20	866	17.8506	.02062	.49995	.39272	.0005773	.0004536
55507	2.63	2.07	504	9.8228	.01949	.25834	.20333	.0005126	.0004034
55605	2.64	1.96	500	10.9180	.02184	.28823	.21400	.0005765	.0004281
55606	2.58	1.49	503	11.0930	.02205	.28580	.16529	.0005690	.0002609
55905	2.67	1.75	331	5.7948	.01751	.15470	.10141	.0004674	.0003064
55906	2.81	1.47	499	7.9968	.01603	.22471	.11755	.0004503	.0002356
55907	2.59	1.61	749	19.3966	.02590	.50238	.31229	.0006707	.0004170
56105	2.73	2.12	336	5.7431	.01709	.15679	.12175	.0004667	.0003622
56106	2.57	2.09	644	12.0161	.01866	.30881	.25174	.0004795	.0003900
56107	2.96	2.23	872	14.4556	.01658	.42790	.32236	.0004907	.0003697
56205	2.51	1.85	333	6.5232	.01959	.16373	.12068	.0004917	.0003624
56208	2.61	1.95	563	13.5720	.02356	.34616	.26465	.0006149	.0004594
56209	2.59	2.21	950	15.8086	.01664	.40945	.34937	.0004310	.0003677
57007	2.65	2.09	88	1.5364	.01746	.04164	.03211	.0004731	.0003649
57406	2.75	2.13	135	2.4923	.01846	.06854	.05309	.0005077	.0003932
57407	2.62	1.86	762	14.9992	.01968	.39297	.27898	.0005157	.0003660
57408	2.61	1.64	596	12.2004	.02047	.31842	.20008	.0005343	.0003557
57506	2.80	2.34	180	2.7616	.01534	.07733	.06462	.0004296	.0003590
57507	2.85	1.55	359	6.9861	.01946	.19905	.10828	.0005545	.0003016
57805	2.87	2.68	270	4.8988	.01814	.14060	.13126	.0005207	.0004861
58805	2.74	2.11	1,158	23.1471	.01999	.63422	.48839	.0005464	.0004218
63106	2.79	2.20	165	3.3006	.02001	.09208	.07261	.0005581	.0004402
66005	2.63	2.18	370	7.6690	.02073	.02017	.16714	.0005451	.0004519
81505	2.94	2.65	146	2.8327	.01940	.08328	.07507	.0005704	.0005141
81706	2.71	2.03	722	15.3928	.02132	.41715	.31248	.0005778	.0004328
Average	2.74	1.79	419.3	8.2271	.01991	.22222	.14658	.0005468	.0003557

3 TO 3.5 PER CENT PROTEID NITROGEN.

Record number.	Proteid nitrogen.	Gliadin-plus-glutenin nitrogen.	Number of kernels.	Kernels.	Average kernel.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in average kernel.
20709	3.05	2.31	258	5.3229	0.02063	0.16235	0.12296	0.0006292	0.0004766
20805	3.32	2.26	697	14.6942	.02157	.48784	.33208	.0006999	.0004875
21205	3.16	.22	123	2.3642	.01922	.07471	.00520	.0006074	.0000423
21208	3.24	2.15	287	5.1594	.01798	.16712	.11093	.0005824	.0003866
21307	3.04	.46	143	2.5691	.01796	.07810	.01182	.0005461	.0000826
21906	3.18	2.10	408	10.4800	.02563	.33402	.22008	.0008168	.0005382
21907	3.35	2.15	158	2.9248	.01851	.09798	.06288	.0006201	.0003980
22206	3 22	2.11	146	2.5712	.01720	.08086	.05425	.0005538	.0003629
22208	3.18	2.14	118	1.9090	.01619	.06071	.04084	.0005144	.0003465
22210	3.17	1.55	298	6.0173	.02019	.19075	.09327	.0006401	.0003129
22211	3.17	1.69	561	11.5675	.02062	.36671	.19548	.0006537	.0003485
26808	3.09	2.28	222	3.8811	.01748	.11992	.08849	.0005402	.0003985
28206	3.07	2.42	219	4.3698	.01996	.13415	.10575	.0006126	.0004830
28806	3.02	1.86	685	14.4630	.02111	.43679	.26901	.0006376	.0003926
33305	3.41	2.41	150	3.1346	.02090	.10689	.07554	.0007126	.0005037
33607	3.22	2.45	136	2.8903	.02125	.09307	.07081	.0006843	.0005206
48306	3.29	2.13	157	2.6571	.01692	.08742	.05660	.0005568	.0003604
48506	3.20	2.17	556	9.4585	.01701	.30267	.20525	.0005444	.0003691

TABLE 19.—*Relation of gliadin-plus-glutenin nitrogen to proteid nitrogen*—Continued.

3 TO 3.5 PER CENT PROTEID NITROGEN—Continued.

Record number.	Percentage of—			Weight (in grams) of—					
	Proteid nitrogen.	Gliadin-plus-glutenin nitrogen.	Number of kernels.	Kernels.	Average kernel.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in average kernel.
48705	3.13	1.56	264	4.3615	0.01652	0.13652	0.06804	0.0005171	0.0002577
48706	3.00	.71	379	6.1983	.01635	.18596	.04401	.0004906	.0001161
55005	3.05	1.99	393	7.9684	.02028	.24303	.15857	.0006185	.0004036
55006	3.16	1.75	451	7.1852	.01593	.22705	.12574	.0005034	.0002788
55508	3.11	1.96	216	3.7407	.01732	.11636	.07332	.0005386	.0003395
57905	3.18	2.92	221	2.4731	.01118	.07859	.07221	.0003556	.0003264
58207	3.09	2.49	307	4.2207	.01375	.13042	.10510	.0004248	.0003424
58705	3.01	2.47	235	2.5436	.01082	.07656	.06283	.0003258	.0002673
Average	3.16	1.95	299.5	5.5817	.01817	.17602	.10889	.0005741	.0003516

3.5 TO 4 PER CENT PROTEID NITROGEN.

Record number.	Proteid nitrogen.	Gliadin-plus-glutenin nitrogen.	Number of kernels.	Kernels.	Average kernel.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in average kernel.
17506	3.52	2.23	93	2.2881	0.02460	0.08044	0.05102	0.0008660	0.0005486
18905	3.81	1,54	103	1.4864	.01443	.05663	.03315	.0005498	.0003218
21811	3.75	2.16	567	11.9114	.02101	.44666	.25728	.0007877	.0004538
21908	3.82	1.88	173	3.5574	.02056	.13589	.06688	.0007855	.0003955
26107	3.92	1.35	144	2.0390	.01416	.07993	.02753	.0005551	.0001912
38505	3.61	1.77	563	12.1088	.02252	.43713	.21432	.0007764	.0003986
42205	3.63	2.73	94	1.8494	.01967	.06713	.05049	.0007142	.0005370
45005	3.58	1.36	235	3.2340	.01376	.11575	.04398	.0004927	.0001871
48505	3.66	1.76	137	1.9154	.01398	.07010	.03371	.0005117	.0002460
66006	3.54	1.38	366	6.0090	.01642	.21272	.08292	.0005812	.0002266
Average	3.68	1.82	247.5	4.6399	.01811	.17024	.08613	.0006620	.0003506

4 TO 4.5 PER CENT PROTEID NITROGEN.

Record number.	Proteid nitrogen.	Gliadin-plus-glutenin nitrogen.	Number of kernels.	Kernels.	Average kernel.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in average kernel.
21812	4.26	2.02	983	14.8137	0.01507	0.63107	0.29934	0.0006420	0.0003044
21813	4.04	2.14	216	4.0258	.01877	.16377	.08615	.0007582	.0004017
21909	4.43	1.98	525	12.1819	.02317	.53889	.29346	.0010265	.0005677
34405	4.33	2.44	207	4.1281	.01994	.17875	.10073	.0008635	.0004865
55007	4.21	2.21	118	2.1571	.01828	.09082	.04767	.0007696	.0004040
76206	4.45	2.03	447	5.4411	.01217	.24213	.11046	.0005417	.0002471
Average	4.29	2.14	416	7.1230	.01790	.20757	.15714	.0007669	.0004019

MORE THAN 4.5 PER CENT PROTEID NITROGEN.

Record number.	Proteid nitrogen.	Gliadin-plus-glutenin nitrogen.	Number of kernels.	Kernels.	Average kernel.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in average kernel.
21206	5.23	0.22	149	2.8564	0.01917	0.14959	0.00628	0.0010026	0.0000422
21210	5.03	1.34	237	3.9143	.01577	.19689	.05245	.0007934	.0002113
40205	4.69	3.07	194	3.6302	.01871	.17026	.11145	.0008776	.0005744
48406	4.87	2.25	249	3.2964	.01324	.16053	.08168	.0006447	.0002979
69805	5.82	1.94	110	2.4420	.02220	.14213	.04738	.0012921	.0004307
72607	5.59	2.51	188	3.4442	.01832	.19253	.08645	.0010241	.0004598
92306	4.93	4.06	347	6.0091	.01732	.29625	.24397	.0008539	.0007032
Average	5.16	2.198	210.6	3.6561	.01782	.18685	.08995	.0009269	.0003885

TABLE 20.—*Summary of analyses, showing relation of gliadin-plus-glutenin nitrogen to proteid nitrogen.*

Range of percentage of proteid nitrogen.	Number of analyses.	Percentage of—		Number of kernels.	Weight (in grams) of—					
		Proteid nitrogen.	Gliadin-plus-glutenin nitrogen.		Kernels.	Average kernel.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in average kernel.	Gliadin-plus-glutenin nitrogen in average kernel
1 to 2	3	1.89	1.76	512.0	10.4207	0.01978	0.19568	0.18667	0.0003744	0.0003518
2 to 2.5	21	2.30	1.68	489.6	10.5874	.02173	.24272	.17872	.0004991	.0003652
2.5 to 3	70	2.74	1.73	419.3	8.2271	.01991	.22222	.13948	.0005468	.0003442
3 to 3.5	26	3.16	1.95	299.5	5.5817	.01817	.17602	.10889	.0005741	.0003516
3.5 to 4	10	3.68	1.82	247.5	4.6399	.01811	.17024	.08613	.0006620	.0003506
4 to 4.5	6	4.29	2.22	416.0	7.1230	.01790	.30757	.15714	.0007669	.0004019
4.5 and over	7	5.16	2.20	210.6	3.6561	.01782	.18685	.08995	.0009269	.0003886

The figures in Table 20 show that while gliadin-plus-glutenin nitrogen increases with proteid nitrogen it does not do so in the same ratio, the increase in proteid nitrogen being due in large measure to an increase in other proteids.

The same analyses are tabulated in Table 21 according to the increase in gliadin-plus-glutenin nitrogen, and the averages for each group are stated in Table 22. In the latter table the increase in proteid nitrogen does not keep pace with the increase in gliadin-plus-glutenin nitrogen, there being 1.74 per cent other proteid nitrogen in the first group and 1.25 per cent in the last.

It thus becomes evident that a determination of proteid nitrogen in the kernel is not an accurate guide to the content of gliadin plus glutenin, and that a direct determination of these substances is necessary.

It is, furthermore, apparent that a determination of gliadin-plus-glutenin nitrogen will permit of the selection of kernels having a large percentage of these substances.

TABLE 21.—*Relation of proteid nitrogen to gliadin-plus-glutenin nitrogen.*

GLIADIN-PLUS-GLUTENIN NITROGEN, 1 TO 1.5 PER CENT.

Record number.	Percentage of—		Number of kernels.	Weight (in grams) of—					
	Gliadin-plus-glutenin nitrogen.	Proteid nitrogen.		Kernels.	Average kernel.	Gliadin plus-glutenin nitrogen in kernels.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in average kernel.	Proteid nitrogen in average kernel.
21210	1.34	5.03	237	3.9143	0.01575	0.05245	0.19689	0.0002113	0.0007934
26107	1.35	3.92	144	2.0390	.01416	.02753	.07993	.0001912	.0005551
27203	1.46	2.36	777	19.1854	.02469	.28010	.45276	.0003605	.0005827
27500	1.09	2.90	243	5.3615	.02206	.05844	.15549	.0002405	.0006399
37705	1.26	2.64	461	8.0905	.01972	.10194	.23998	.0002485	.0005327
38005	1.23	2.84	139	2.5134	.01808	.03091	.07138	.0002224	.0005135
38016	1.39	2.63	401	8.4605	.02110	.11760	.22251	.0002933	.0005549
38001	1.34	2.74	293	6.7665	.02309	.09067	.18540	.0003094	.0006479
39407	1.44	2.88	447	9.3541	.02093	.13470	.21399	.0003014	.0006027
43405	1.18	2.92	124	2.8000	.02258	.03304	.08176	.0002664	.0006594
44006	1.29	2.90	124	2.5235	.02035	.03255	.07318	.0002625	.0005902
45005	1.36	3.58	235	3.2340	.01376	.04398	.11575	.0001871	.0004927
55001	1.49	2.58	505	11.0930	.02205	.16529	.28580	.0002609	.0005690
55906	1.47	2.81	499	7.9968	.01603	.11755	.22471	.0002356	.0004503
60006	1.38	3.54	366	6.0090	.01642	.08292	.21272	.0002266	.0005812
Average	1.34	3.08	333	6.6228	.01939	.09198	.18748	.0002545	.0005843

TABLE 21.—*Relation of proteid nitrogen to gliadin-plus-glutenin nitrogen*—Continued.

GLIADIN-PLUS-GLUTENIN NITROGEN, 1.5 TO 2 PER CENT.

Record number.	Percentage of—		Number of kernels.	Weight (in grams) of—					
	Gliadin-plus-glutenin nitrogen.	Proteid nitrogen.		Kernels.	Average kernel.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in average kernel.	Proteid nitrogen in average kernel.
18905	1.54	3.81	103	1.4864	0.01443	0.03315	0.05663	0.0003218	0.0005498
20707	1.85	2.77	444	9.9070	.02282	.18328	.27443	.0004128	.0006181
21305	1.97	2.67	312	6.2514	.02004	.12315	.16691	.0003948	.0005350
21808	1.96	2.57	1,156	19.7446	.01708	.38700	.50744	.0003348	.0004389
21908	1.88	3.82	173	3.5574	.02056	.06688	.13589	.0003955	.0007855
21909	1.98	4.43	525	12.1819	.02317	.29846	.53889	.0005677	.0010265
22205	1.97	2.81	283	2.6965	.00953	.05312	.07577	.0001877	.0002677
22207	1.82	2.77	169	3.2787	.01940	.05967	.09082	.0003531	.0005376
22210	1.55	3.17	298	6.0173	.02019	.09327	.19075	.0003129	.0006401
22211	1.69	3.17	561	11.5675	.02062	.19548	.36671	.0003485	.0006537
26906	1.82	2.71	228	4.2376	.01859	.07712	.11484	.0003383	.0005037
26909	1.88	2.80	180	2.9999	.01667	.05640	.08400	.0003134	.0004667
27005	1.90	2.63	866	16.4120	.01895	.31182	.43164	.0003600	.0004984
27205	1.70	2.41	891	16.4061	.01841	.27890	.39539	.0003130	.0004437
27207	1.95	2.92	166	3.3266	.02004	.06487	.09712	.0003908	.0005850
27305	1.73	2.58	267	5.5666	.02085	.09630	.14362	.0003607	.0005379
27505	1.65	2.12	539	12.0399	.02183	.19866	.24942	.0003602	.0004627
27506	1.98	2.70	444	10.0005	.02252	.19800	.27003	.0004459	.0006082
28805	1.55	2.91	87	2.1851	.02572	.03887	.06359	.0003894	.0007309
28806	1.86	3.02	685	14.4630	.02111	.26901	.43679	.0003926	.0006376
33605	1.92	2.39	301	7.0596	.02345	.13554	.16872	.0004502	.0005605
38505	1.77	3.61	563	12.1088	.02252	.21432	.43713	.0003986	.0007764
38608	1.73	2.82	158	3.0228	.01913	.05229	.08522	.0003309	.0005394
39205	1.84	2.11	1,031	21.5399	.02089	.39635	.45435	.0003844	.0004407
48106	1.80	2.38	608	11.6655	.01919	.20997	.27765	.0003454	.0004567
48305	1.77	2.87	473	12.0278	.02543	.21289	.34524	.0004501	.0007299
48409	1.50	2.02	314	6.4302	.02048	.09645	.12989	.0003072	.0004137
48505	1.76	3.66	137	1.9154	.01398	.03371	.07010	.0002460	.0005117
48705	1.56	3.13	264	4.3615	.01652	.06804	.13652	.0002577	.0005171
55005	1.99	3.05	393	7.9684	.02028	.15857	.24303	.0004036	.0006185
55006	1.75	3.16	451	7.1852	.01593	.12574	.22705	.0002788	.0005034
55008	1.58	2.60	944	17.4226	.01846	.27528	.45299	.0002917	.0004799
55206	1.87	2.57	578	11.3592	.01965	.21241	.29079	.0003675	.0005031
55305	1.97	2.48	167	2.5160	.01507	.04957	.06240	.0002969	.0003736
55307	1.56	1.89	342	5.6864	.01663	.08871	.10747	.0002599	.0003142
55508	1.96	3.11	216	3.7407	.01732	.07332	.11636	.0003395	.0005386
55605	1.96	2.64	500	10.9180	.02184	.21400	.28823	.0004281	.0005765
55905	1.75	2.67	331	5.7948	.01751	.10141	.15470	.0003064	.0004674
55907	1.61	2.59	749	19.3966	.02590	.31229	.50238	.0004170	.0006707
55908	1.96	2.42	562	12.2210	.02175	.23953	.29575	.0004263	.0005262
55909	1.66	2.30	302	9.2120	.03050	.15292	.21187	.0005063	.0007016
56205	1.85	2.51	333	6.5232	.01959	.12068	.16373	.0003624	.0004917
56206	1.95	2.42	509	9.3093	.01829	.18153	.22529	.0003566	.0004426
56207	1.83	2.34	462	10.9073	.03361	.19960	.25522	.0004321	.0005524
56208	1.95	2.61	563	13.5720	.02356	.26465	.34616	.0004594	.0006149
57407	1.86	2.62	762	14.9992	.01968	.27898	.39297	.0003660	.0005157
57408	1.64	2.61	596	12.2004	.02047	.20008	.31842	.0003357	.0005343
57507	1.55	2.85	359	6.9861	.01946	.10828	.19905	.0003016	.0005545
65306	1.68	2.41	544	9.8298	.01807	.16514	.23690	.0003036	.0004355
65307	1.81	2.28	373	7.0051	.01878	.12680	.15971	.0003399	.0004282
65308	1.95	2.09	583	11.7066	.02008	.22828	.24468	.0003916	.0004197
69805	1.94	5.82	110	2.4420	.02220	.04738	.14213	.0004307	.0002921
80305	1.76	1.81	729	15.7835	.02165	.27937	.28569	.0003832	.0003919
81705	1.96	1.98	465	9.7922	.02106	.19193	.19388	.0004128	.0004170
81708	1.64	2.41	287	7.3993	.02578	.12135	.17833	.0004228	.0006213
Average	1.80	2.76	442.5	9.0243	.02016	.16392	.23801	.0003653	.0005538

GLIADIN-PLUS-GLUTENIN NITROGEN, 2 TO 2.5 PER CENT.

Record number.	Gliadin-plus-glutenin nitrogen.	Proteid nitrogen.	Number of kernels.	Kernels.	Average kernel.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in average kernel.	Proteid nitrogen in average kernel.
17506	2.23	3.52	93	2.2881	0.02460	0.05102	0.08044	0.0005486	0.0008660
20706	2.05	2.78	163	3.3138	.02033	.06793	.09212	.0004168	.0005652
20709	2.31	3.05	258	5.3229	.02063	.12296	.16235	.0004766	.0006292
20710	2.00	2.83	867	17.1115	.01974	.34222	.48428	.0003948	.0005586
20805	2.26	3.32	697	14.6942	.02157	.33208	.48784	.0004875	.0006999
21208	2.15	3.24	287	5.1594	.01798	.11093	.16712	.0003866	.0005824
21807	2.11	2.73	377	9.4172	.02498	.19870	.25709	.0005271	.0006664
21809	2.18	2.73	418	8.0214	.01919	.17487	.21898	.0004183	.0005238
21811	2.16	3.75	567	11.9114	.02101	.25728	.44666	.0004538	.0007877
21812	2.02	4.26	983	14.8139	.01507	.29934	.63107	.0003044	.0006420
21813	2.14	4.04	216	4.0258	.01877	.08615	.16377	.0004017	.0007582
21905	2.18	2.64	791	14.3111	.01809	.31198	.37781	.0003944	.0004777

TABLE 21.—*Relation of proteid nitrogen to gliadin-plus-glutenin nitrogen*—Continued.

GLIADIN-PLUS-GLUTENIN NITROGEN, 2 TO 2.5 PER CENT—Continued.

Record number.	Percentage of—		Number of kernels.	Weight (in grams) of—					
	Gliadin-plus-glutenin nitrogen.	Proteid nitrogen.		Kernels.	Average kernel.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in average kernel.	Proteid nitrogen in average kernel.
21906	2.10	3.18	408	10.4800	0.02563	0.22008	0.33403	0.0005382	0.0008168
21907	2.15	3.35	158	2.9248	.01851	.06288	.09798	.0003980	.0006201
22206	2.11	3.22	146	2.5712	.01720	.05425	.08086	.0003629	.0005538
22208	2.14	3.10	118	1.9090	.01619	.04084	.06071	.0003465	.0005144
26808	2.28	3.09	222	3.8811	.01748	.08849	.11992	.0003985	.0005402
26905	2.09	2.76	326	6.4102	.01966	.13398	.17692	.0004109	.0005427
26908	2.16	2.96	192	3.9797	.02073	.08596	.11780	.0004478	.0006135
27508	2.32	2.64	251	5.5324	.02287	.12835	.14608	.0005306	.0006037
28206	2.42	3.07	219	4.3698	.01996	.10575	.13415	.0004830	.0006126
33107	2.12	2.35	318	6.1026	.01919	.12643	.14341	.0004163	.0004510
33305	2.41	3.41	150	3.1346	.02090	.07554	.10689	.0005037	.0007126
33607	2.45	3.22	136	2.8902	.02125	.07081	.09307	.0005206	.0006843
34405	2.44	4.33	207	4.1281	.01994	.10073	.17875	.0004865	.0008635
37305	2.29	2.96	309	6.1394	.01987	.14060	.18173	.0004550	.0005881
37707	2.10	2.93	193	3.3004	.01710	.06931	.09670	.0003591	.0005010
39506	2.06	2.93	67	1.9218	.02869	.03959	.05631	.0005910	.0008404
40505	2.19	2.82	170	4.1546	.02444	.09099	.11716	.0005352	.0006892
46107	2.08	2.54	478	8.3935	.01756	.17458	.21319	.0003652	.0004460
48306	2.13	3.29	157	2.6571	.01692	.05660	.08742	.0003604	.0005568
48406	2.25	4.87	249	3.2964	.01324	.08168	.16053	.0002979	.0006447
48506	2.17	3.20	556	9.4585	.01701	.20525	.30267	.0003691	.0005444
55007	2.21	4.21	118	2.1571	.01828	.04767	.09082	.0004040	.0007696
55506	2.20	2.80	866	17.8506	.02062	.39272	.49995	.0004536	.0005773
55507	2.07	2.63	504	9.8228	.01949	.20333	.25834	.0004034	.0005126
56105	2.12	2.73	336	5.7431	.01709	.03503	.15679	.0001042	.0004667
56106	2.09	2.57	644	12.0161	.01866	.05768	.30881	.0000896	.0004795
56107	2.23	2.96	872	14.4556	.01658	.10553	.42792	.0001210	.0004907
56209	2.21	2.59	950	15.8086	.01664	.34937	.40945	.0003677	.0004310
57007	2.09	2.65	168	1.5364	.01746	.03211	.04164	.0003649	.0004731
57406	2.13	2.75	135	2.4923	.01846	.05309	.06854	.0003932	.0005077
57506	2.34	2.80	180	2.7616	.01534	.06462	.07733	.0003590	.0004296
57508	2.05	2.21	380	12.0728	.03177	.24750	.26680	.0006513	.0007021
58207	2.49	3.09	307	4.2207	.01375	.10510	.13042	.0003424	.0004248
58705	2.47	3.01	235	2.5436	.01082	.06283	.07656	.0002673	.0003258
58805	2.11	2.74	1,158	23.1471	.01999	.48839	.63422	.0004218	.0005464
63106	2.20	2.79	165	3.3006	.02001	.07261	.09208	.0004402	.0005581
66005	2.18	2.63	370	7.6690	.02073	.16714	.20170	.0004519	.0005451
74606	2.05	2.30	464	9.6451	.02079	.19772	.22184	.0004262	.0004781
76206	2.03	4.45	447	5.4411	.01217	.11046	.24213	.0002471	.0005417
81706	2.03	2.71	722	15.3928	.02132	.31248	.41715	.0004328	.0005778
Average	2.18	3.08	380.1	7.2520	.01935	.14641	.21535	.0004063	.0005872

GLIADIN-PLUS-GLUTENIN NITROGEN, 2.5 TO 3 PER CENT.

42205	2.73	3.63	94	1.8494	0.01967	0.050049	0.06713	0.0005370	0.0007142
57805	2.68	2.87	270	4.8988	.01814	.13126	.14060	.0004861	.0005207
57905	2.92	3.18	221	2.4731	.01118	.07221	.07859	.0003264	.0003556
72607	2.51	5.59	188	3.4442	.01832	.08645	.19253	.0004598	.0010241
81505	2.65	2.94	146	2.8327	.01940	.7507	.08328	.0005141	.0005704
Average	2.698	3.64	183.8	3.0696	.01734	.08310	.11243	.0004647	.0006370

GLIADIN-PLUS-GLUTENIN NITROGEN, 3 PER CENT AND OVER.

40205	3.07	4.69	194	3.6302	0.01871	0.11145	0.17026	0.0005744	0.0008776
92706	4.06	4.93	347	6.0091	.01732	.24397	.29625	.0007032	.0008539
Average	3.56	4.81	270.5	4.8196	.01801	.17771	.23325	.0006388	.0008657

TABLE 22.—*Summary of analyses, showing relation of proteid nitrogen to gliadin-plus-glutenin nitrogen.*

Range of percentage of gliadin-plus-glutenin nitrogen.	Percentage of—		Number of—		Weight (in grams) of—					
	Gliadin-plus-glutenin nitrogen.	Proteid nitrogen.	Analyses.	Kernels.	Kernels.	Average kernel.	Gliadin-plus-glutenin nitrogen in kernels.	Proteid nitrogen in kernels.	Gliadin-plus-glutenin nitrogen in average kernel.	Proteid nitrogen in average kernel.
1 to 1.5.......	1.34	3.08	15	333	6.6228	0.01939	0.09198	0.18748	0.0002545	0.0005843
1.5 to 2.......	1.80	2.76	55	442.5	9.0243	.02016	.16392	.23801	.0003653	.0005538
2 to 2.5.......	2.18	3.08	52	380.1	7.2520	.01935	.14641	.21535	.0004063	.0005872
2.5 to 3.......	2.70	3.64	5	183.8	3.0696	.01734	.08310	.11243	.0004647	.0006570
3 and over....	3.56	4.81	2	270.5	4.8196	.01801	.17771	.23325	.0006388	.0008657

IMPROVEMENT IN THE QUALITY OF THE GLUTEN.

It is well known that large differences exist in the bread-making values of different varieties of wheats even when they have approximately the same gluten content and are raised in the same locality. This fact is generally attributed to differences in the quality of the gluten.

W. Farrar[a] points out the difference in the bread-making qualities of two wheats due to the quality of the gluten. He compares Saxon Fife wheat, which had a gluten content of 9.92 per cent, and which produced 309 pounds of bread from 200 pounds of flour, with Purple Straw Tuscan wheat, which had a gluten content of 9.94 per cent, and which produced only 278 pounds of bread from the same quantity of flour.

In this case it was not the amount but the quality of the gluten that determined the greater excellence of the Saxon Fife wheat.

It has further been stated by Girard,[b] Snyder,[c] and Guthrie[d] that the ratio in which gliadin and glutenin exist in the gluten determines its value for bread making.

It was considered desirable to ascertain whether the proportions of these two constituents remain about the same in wheats of high and of low content. If the quality of the gluten remains constant as the quantity increases, the value of the wheat for bread making will improve in about the same ratio. If, on the other hand, there is a tendency for the quality to deteriorate as the quantity increases, there would be greater difficulty in effecting improvement.

In Table 23, analyses of the crop of 1903 are arranged in groups according to their content of gliadin plus glutenin. The first group comprises all plants having less than 1 per cent, and each succeeding group increases by 0.25 per cent. It is followed by Table 24, which is a summary of Table 23.

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[a] Agricultural Gazette of New South Wales, 9 (1898), pp. 241–250.

[b] Compt. Rend., 1897, p. 876.

[c] Minnesota Experiment Station Bulletins 54 and 63.

[d] Agricultural Gazette of New South Wales, 9 (1898), pp. 363–374.

TABLE 23.—*Ratio of gliadin to glutenin as the content of their sum increases.*

GLIADIN-PLUS-GLUTENIN NITROGEN, BELOW 1 PER CENT.

Record number.	Percentage of			Proportion of—		Percentage of—	
	Gliadin-plus-glutenin nitrogen.	Gliadin nitrogen.	Glutenin nitrogen.	Gliadin	Glutenin.	Proteid nitrogen.	Other proteid nitrogen.
21205	0.216	0.114	0.102	0.528	0.472	3.16	2.944
21206	.218	.142	.076	.651	.349	5.23	5.012
21207	.170	.099	.071	.582	.418	2.96	2.790
21212	.192	.109	.083	.567	.433	2.16	1.968
21306	.975	.505	.470	.518	.482	2.90	1.925
21307	.461	.255	.206	.447	.553	3.04	2.579
21805	.230	.126	.104	.548	.452	2.69	2.460
27307	.821	.806	.015	.982	.018	2.53	1.709
48806	.748	.018	.730	.024	.976	2.70	1.952
55308	.655	.629	.026	.960	.040	2.54	1.885
81707	.636	.237	.399	.372	.628	2.34	1.704
Average	.484	.276	.208	.562	.438	2.93	2.448
GLIADIN-PLUS-GLUTENIN NITROGEN. 1 TO 1.25 PER CENT.							
27509	1.087	1.072	0.015	0.986	0.014	2.90	1.813
38005	1.227	.593	.634	.483	.517	2.84	1.613
43405	1.184	1.078	.106	.910	.090	2.92	1.736
Average	1.166	.914	.252	.793	.207	2.89	1.721
GLIADIN-PLUS-GLUTENIN NITROGEN, 1.25 TO 1.50 PER CENT.							
26107	1.352	0.108	1.244	0.080	0.920	3.92	2.568
27206	1.465	.815	.650	.556	.444	2.36	.895
37705	1.265	.715	.550	.565	.435	2.64	1.375
38606	1.387	.725	.662	.522	.478	2.63	1.243
38609	1.336	.586	.750	.439	.561	2.74	1.404
39405	1.439	.818	.621	.568	.432	2.88	1.441
44606	1.287	1.057	.230	.821	.179	2.90	1.613
45005	1.361	1.240	.121	.911	.089	3.58	2.219
55606	1.493	.899	.594	.602	.398	2.58	1.087
55906	1.470	.443	1.027	.301	.699	2.81	1.340
Average	1.385	.741	.645	.536	.463	2.90	1.518
GLIADIN-PLUS-GLUTENIN NITROGEN, 1.50 TO 1.75 PER CENT.							
18905	1.537	0.143	1.394	0.093	0.907	3.81	2.273
22210	1.555	.801	.754	.515	.485	3.17	1.615
22211	1.692	1.002	.690	.592	.408	3.17	1.478
27205	1.700	1.073	.627	.631	.369	2.41	.710
27305	1.735	1.075	.660	.619	.381	2.58	.845
27505	1.651	1.032	.619	.625	.375	2.12	.469
28805	1.555	.958	.597	.616	.384	2.91	1.355
38608	1.731	.962	.769	.556	.444	2.82	1.089
48409	1.504	.690	.814	.459	.541	2.02	.516
48705	1.563	.057	1.506	.036	.964	3.13	1.567
55008	1.581	.687	.894	.435	.565	2.60	1.019
55307	1.561	.908	.653	.582	.418	1.89	.329
55907	1.608	.632	.976	.393	.607	2.59	.982
55909	1.658	.810	.848	.488	.512	2.30	.642
57408	1.639	1.177	.462	.717	.283	2.61	.971
57507	1.546	1.141	.405	.738	.262	2.85	1.304
65306	1.683	.965	.718	.573	.427	2.41	.727
81708	1.641	1.221	.420	.744	.256	2.41	.769
Average	1.619	.852	.767	.523	.477	2.65	1.037

TABLE 23.—*Ratio of gliadin to glutenin as the content of their sum increases*—Continued.

GLIADIN-PLUS-GLUTENIN NITROGEN, 1.75 TO 2 PER CENT.

Record number.	Percentage of—			Proportion of—		Percentage of—	
	Gliadin-plus-glutenin nitrogen.	Gliadin nitrogen.	Glutenin nitrogen.	Gliadin.	Glutenin.	Proteid nitrogen.	Other proteid nitrogen.
20707	1.855	1.046	0.809	0.564	0.436	2.77	0.915
20710	1.995	1.125	.871	.564	.436	2.83	.834
21305	1.969	1.049	.920	.533	.467	2.67	.701
21808	1.963	1,046	.917	.533	.467	2.57	.607
21908	1.876	1.015	.861	.541	.459	3.82	1.944
21909	1.976	1.367	.609	.697	.303	4.43	2.454
22205	1.969	1.185	.784	.602	.398	2.81	.841
26906	1.819	.988	.831	.543	.457	2.71	.891
26909	1.879	.996	.883	.531	.469	2.80	.921
27005	1.904	1.066	.838	.559	.441	2.63	.726
27207	1.946	1.278	.668	.652	.348	2.92	.974
27506	1.977	1.147	.830	.580	.420	2.70	.723
28806	1.864	.902	.962	.484	.516	3.02	1.156
33605	1.919	1.124	.795	.585	.415	2.39	.471
38505	1.766	.862	.904	.488	.512	3.61	1.844
39205	1.845	1.117	.728	.605	.395	2.11	.265
48106	1.805	1.035	.770	.573	.427	2.38	.575
48305	1.766	.996	.770	.564	.436	2.87	1.104
48505	1.757	.965	.792	.549	.451	3.66	1.903
55005	1.987	1.102	.885	.555	.445	3.05	1.063
55006	1.754	1.099	.655	.626	.374	3.16	1.406
55206	1.866	.840	1.026	.450	.550	2.56	.694
55305	1.974	1.042	.932	.528	.472	2.48	.506
55508	1.959	1.037	.922	.529	.471	3.11	1.151
55605	1.959	1.044	.915	.533	.467	2.64	.681
55905	1.750	.575	1.175	.328	.672	2.67	.920
55908	1.957	1.075	.882	.549	.451	2.42	.463
56205	1.850	.883	.967	.477	.523	2.51	.660
56206	1.949	1.089	.860	.559	.441	2.42	.471
56207	1.827	.987	.840	.540	.460	2.34	.513
56208	1.946	1.127	.819	.579	.421	2.61	.664
57407	1.858	.935	.923	.503	.497	2.62	.762
65307	1.815	1.052	.763	.579	.421	2.28	.465
65308	1.946	1.090	.856	.560	.440	2.09	.144
69805	1.937	1.142	.795	.589	.411	5.82	3.883
80305	1.770	1.159	.611	.661	.339	1.81	.040
81705	1.956	1.048	.908	.535	.465	1.98	.024
Average	1.889	1.044	.845	.552	.448	2.82	.929

GLIADIN-PLUS-GLUTENIN NITROGEN, 2 TO 2.25 PER CENT.

17506	2.226	1.458	0.768	0.655	0.345	3.52	1.294
20706	2.053	1.089	.964	.530	.470	2.78	.727
21208	2.146	1.154	.992	.537	.463	3.24	1.094
21807	2.110	1.174	.936	.556	.444	2.73	.620
21809	2.178	1.183	.995	.543	.457	2.73	.552
21811	2.156	1.144	1.012	.531	.469	3.75	1.594
21812	2.023	1.139	.884	.563	.437	4.26	2.237
21813	2.141	1.045	1.096	.488	.512	4.04	1.899
21905	2.181	1.344	.837	.616	.384	2.64	.459
21906	2.096	1.208	.888	.576	.424	3.18	1.084
21907	2.146	1.187	.959	.553	.447	3.35	1.204
22206	2.113	1.271	.842	.601	.399	3.22	1.107
22208	2.142	1.309	.833	.611	.389	3.18	1.038
26905	2.087	1.197	.890	.573	.427	2.76	.673
26908	2.158	1.250	.908	.579	.421	2.96	.802
33107	2.123	1.283	.840	.604	.396	2.35	.227
37707	2.097	1.044	1.053	.498	.502	2.93	.833
39506	2.065	1.281	.784	.620	.380	2.93	.865
40505	2.189	1.143	1.046	.522	.478	2.82	.631
46107	2.076	1.164	.912	.561	.439	2.54	.464
48306	2.135	1.130	1.005	.529	.471	3.29	1.155
48406	2.249	1.290	.959	.574	.426	4.87	2.621
48506	2.171	1.104	1.067	.508	.492	3.20	1.029
55007	2.211	1.248	.963	.564	.436	4.21	1.999
55506	2.197	1.136	1.061	.517	.483	2.80	.603
55507	2.070	1.079	.991	.521	.479	2.63	.560
56105	2.118	1.277	.841	.603	.397	2.73	.612
56106	2.091	1.091	1.000	.522	.478	2.57	.479
56107	2.234	1.033	1.201	.462	.538	2.96	.726
56209	2.208	1.161	1.047	.526	.474	2.79	.582

TABLE 23.—*Ratio of gliadin to glutenin as the content of their sum increases*—Continued.

GLIADIN-PLUS-GLUTENIN NITROGEN, 2 TO 2.25 PER CENT—Continued.

Record number.	Percentage of—			Proportion of—		Percentage of—	
	Gliadin-plus-glutenin nitrogen.	Gliadin nitrogen.	Glutenin nitrogen.	Gliadin.	Glutenin.	Proteid nitrogen.	Other proteid nitrogen.
57007	2.093	1.159	0.934	0.553	0.447	2.65	0.557
57406	2.134	1.080	1.054	.506	.494	2.75	.616
57508	2.053	1.124	.929	.547	.453	2.21	.157
58805	2.112	1.060	1.052	.501	.499	2.74	.628
63106	2.199	1.186	1.013	.539	.461	2.79	.591
66005	2.181	1.142	1.039	.528	.472	2.63	.449
74606	2.046	1.016	1.030	.496	.504	2.30	.254
76206	2.029	1.223	.806	.602	.398	4.45	2.421
81706	2.034	1.701	.333	.816	.184	2.71	.676
Average	2.130	1.187	.943	.557	.443	3.05	.921

GLIADIN-PLUS-GLUTENIN NITROGEN, 2.25 TO 2.50 PER CENT.

20709	2.313	1.307	1.006	0.565	0.435	3.05	0.737
20805	2.259	1.215	1.044	.538	.462	3.32	1.061
26808	2.281	1.377	.904	.604	.396	3.09	.809
27508	2.324	1.247	1.077	.537	.463	2.64	.316
28206	2.424	1.366	1.058	.563	.437	3.07	.646
33305	2.407	1.182	1.225	.491	.509	3.41	1.003
33607	2.446	1.391	1.055	.569	.431	3.22	.774
34405	2.443	1.230	1.213	.503	.497	4.33	1.887
37305	2.293	1.208	1.085	.527	.473	2.96	.667
57506	2.344	1.203	1.141	.511	.489	2.80	.456
58207	2.492	1.313	1.179	.526	.474	3.09	.598
58705	2.467	1.195	1.272	.484	.516	3.01	.543
Average	2.374	1.268	1.105	.535	.465	3.16	.791

GLIADIN-PLUS-GLUTENIN NITROGEN, 2.50 PER CENT AND OVER.

40205	3.069	1.850	1.219	0.603	0.397	4.69	1.621
42205	2.728	1.480	1.248	.542	.458	3.63	.902
57805	2.684	1.303	1.381	.485	.515	2.87	.186
57905	2.918	1.573	1.345	.539	.461	3.18	.262
72607	2.515	1.459	1.056	.579	.421	5.59	3.075
81505	2.652	1.066	1.586	.401	.599	2.94	.288
92306	4.063	2.388	1.675	.587	.413	4.93	.867
Average	2.947	1.588	1.358	.534	.466	3.98	1.029

TABLE 24.—*Summary of analyses, showing the ratio of gliadin to glutenin as the content of their sum increases.*

Range of percentage of gliadin-plus-glutenin nitrogen.	Percentage of gliadin-plus-glutenin nitrogen.	Number of analyses.	Percentage of—		Proportion of—		Percentage of—	
			Gliadin nitrogen.	Glutenin nitrogen.	Gliadin.	Glutenin.	Proteid nitrogen.	Other proteid nitrogen.
Below 1	0.484	11	0.276	0.208	0.562	0.438	2.93	2.448
1 to 1.25	1.166	3	.914	.252	.793	.207	2.89	1.721
1 25 to 1.50	1.385	10	.741	.645	.536	.463	2.90	1.518
1.50 to 1.75	1.619	18	.852	.767	.523	.477	2.65	1.037
1.75 to 2	1.889	37	1.044	.845	.552	.448	2.82	.929
2 to 2.25	2.130	39	1.187	.943	.557	.443	3.05	.921
2.25 to 2.50	2.374	12	1.268	1.105	.535	.465	3.16	.791
2.50 and over	2.947	7	1.588	1.358	.534	.466	3.98	1.029

It will be seen from Table 24 that the ratio of gliadin to glutenin remains practically the same as the percentage of their sum increases. It would therefore be safe to assume that an increase in the gluten content of a given variety of wheat raised in the same region would carry with it a corresponding improvement in its value for bread making, although there might be fluctuations from year to year in quality of gluten, as there is in the quantity.

If the quality of gluten is determined by the ratio of gliadin and glutenin of which it is composed, it is likely that there is some certain proportion that is most desirable. Unfortunately, the investigators who have taken up this subject do not by any means agree upon the proper ratio. Should this be ascertained there would be ample opportunity for the selection of individual plants in which the proportion of gliadin and glutenin would approximate the ideal. There would thus be possible a much more rapid improvement in the quality of wheat than can be accomplished by confining selection to an increase in the gluten.

An obstacle to the usefulness of these determinations in the whole wheat appears in the announcement by Nasmith, already cited, that while gliadin occurs in all portions of the endosperm, glutenin does not appear in the aleurone cells. That being the case, it is difficult to believe that any given ratio between these constituents in the whole wheat could be taken as the one most desirable. The ratio in the gluten alone may, however, have an important influence on its quality, and a certain definite proportion of each may produce an ideal gluten.

In the light of the present knowledge on the subject, a mechanical determination of gluten would seem to be most useful, if it can be made with such small quantities of wheat as are obtained from single plants, while determinations of gliadin and glutenin in the gluten would afford a means of judging of its quality.

SOME RESULTS OF BREEDING TO INCREASE THE CONTENT OF PROTEID NITROGEN.

Selected plants have been grown on a large scale for two years. From these results it is very apparent that a high percentage of nitrogen and the qualities that go with it are transmissible from one generation to another.

In Table 25 are analyses of the plants of the crop of 1902, grouped according to their proteid nitrogen content into classes of from 1 to 2 per cent, 2 to 2.5 per cent, and increasing by 0.5 per cent up to 4.5 per cent and above. Opposite the plant number of each plant of the crop of 1902 are stated its percentage of proteid nitrogen and weight of proteid nitrogen in kernels. On the same line are the plant numbers for the entire progeny in 1903, and following these are the percentage of proteid nitrogen, weight of proteid nitrogen per average kernel, and average weight of kernel for all of these progeny.

The averages for each group are given in Table 26.

TABLE 25.—*Analyses showing transmission of nitrogen from one generation to another.*[a]

1 TO 2 PER CENT PROTEID NITROGEN.

1902				1903			
Record number.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).	Record number.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).
32201	1.51	....	....	32206-7	2.64	0.0010055	0.03874
32601	1.99	....	....	32605-6 and 8	2.62	.0015963	.07560
63501	1.98	....	....	63505-6	2.17	.0007499	.03502
69501	1.94	....	....	69505-6	2.39	.0009348	.03894
69701	1.97	....	....	69705	2.50	.0003874	.01550
73301	1.12	....	....	73306-8	2.586	.0016918	.06582
91901	1.83	....	....	91905-6	3.09	.0010830	.03513
92401	1.33	....	....	92405-9	2.628	.0024129	.09109
92901	1.67	....	....	92905-9	2.814	.0024540	.08814
94101	1.38	....	....	94105	2.67	.0006790	.02543
94201	1.63	....	....	94205-9	2.576	.0022132	.08738
94401	1.73	....	....	94406-7	2.27	.0008092	.03538
94601	1.89	....	....	94605-6	1.87	.0016125	.08851
94901	1.99	....	....	94905-9	2.85	.0025361	.08899
95501	1.92	....	....	95505-10	2.498	.0026506	.10605
Average	1.658	....	....	Average	2.587	.0004960	.019907

2 TO 2.5 PER CENT PROTEID NITROGEN.

17401	2.45	....	....	1740[5-6] [8-10]	2.646	0.0025803	0.09807
34201	2.28	....	....	34205-8	2.857	.0023077	.08075
57301	2.33	0.000601	0.02585	57305-8	2.54	.0018351	.07010
Average	2.353	.000601	.02585	Average	2.68	.00051716	.019146

2.5 TO 3 PER CENT PROTEID NITROGEN.

21701	2.50	....	....	21705-11	2.78	0.0042343	0.15101
33401	2.73	....	....	33405-8	1.977	.0014277	.07274
Average	2.615	....	....	Average	2.487	.0005147	.02032

3 TO 3.5 PER CENT PROTEID NITROGEN.

17301	3.04	....	....	17305-8	3.207	0.0025519	0.07920
17501	3.14	....	....	17505-7	4.006	.0021778	.05595
18901	3.31	....	....	18905-6	3.64	.0010439	.02863
20701	3.22	....	....	20705-10	2.86	.0034181	.12074
20801	3.49	....	....	20805	3.32	.0006999	.02157
21301	3.05	....	....	21305-8	3.015	.0021798	.07278
21801	3.10	....	....	21805-13	3.13	.0054513	.17668
21901	3.17	....	....	2190[5-9] [11-13]	3.527	.0060008	.16783
26901	3.28	....	....	26905-9	2.768	.0025943	.09357
27001	3.24	....	....	27005	2.63	.0004984	.01895
27201	3.12	....	....	27205-7	2.56	.0016114	.06314
27301	3.00	....	....	27305-8	2.93	.0022229	.07654
28801	3.31	....	....	28805-6	2.96	.0013685	.04623
33101	3.06	....	....	33105-7	2.73	.0015199	.05574
33301	3.33	....	....	33305	3.41	.0007126	.02090
33601	3.22	....	....	33605-7	2.606	.0017186	.06614
34401	3.08	0.000909	0.02956	34405	4.33	.0008635	.01994
34601	3.46	.000948	.02749	34606	3.12	.0006904	.02213
36901	3.18	.000827	.02602	36905	3.88	.0007295	.01880
37301	3.13	.000854	.02731	37305	2.96	.0005881	.01987
37701	3.44	.000685	.01995	37705-7	2.636	.0015390	.05837
37901	3.21	.000831	.02599	37905-6	2.48	.0009112	.03641
38501	3.09	.000844	.02732	38505-6	3.25	.0013476	.04227
38701	3.33	.000693	.02081	38706	2.59	.0005148	.01988
39401	3.31	.000933	.02820	39405	2.88	.0006027	.02093
40201	3.11	.001017	.03271	40205	4.69	.0008776	.01871
40301	3.11	.000914	.02942	40305	3.11	.0006255	.02011

[a] In this table the average percentage of proteid nitrogen for all plants raised in 1903, resulting from plants of 1 to 2 per cent, 2 to 2.5 per cent, etc., in 1902 is determined by adding together analyses of all plants in that group and dividing by the total number, irrespective of families.

TABLE 25.—*Analyses showing transmission of nitrogen from one generation to another*—Continued.

3 TO 3.5 PER CENT PROTEID NITROGEN—Continued.

1902				1903			
Record number.	Percentage of proteid nitrogen in kernel.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).	Record number.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).
40401	3.32	0.001039	0.03136	40405	3.17	0.0004352	0.01373
40501	3.23	.001050	.03250	40505	2.82	.0006892	.02444
42201	3.46	.000972	.02813	42205-6	2.54	.0008988	.03231
42901	3.37	.000933	.02766	42905	3.17	.0005447	.01866
43401	3.24	.000907	.02800	43405	2.92	.0006594	.02258
43501	3.37	.000772	.02299	43505	4.13	.0006423	.01555
44601	3.33	.000899	.02701	44605-7	2.73	.0016171	.05890
48101	3.16	.000853	.02704	48106	2.38	.0004567	.01919
48301	3.49	.001005	.02882	48305-6	3.08	.0012867	.04235
48501	3.16	.000866	.02748	48505-8	3.065	.0021750	.07253
48701	3.36	.000820	.02445	48705-6	3.06	.0010077	.03287
48801	3.43	.000888	.02595	48806	2.70	.0004877	.01798
49501	3.19	.000791	.02488	49505	3.24	.0006149	.01898
50701	3.36	.000937	.02797	50705-6	3.17	.0010793	.03329
51001	3.33	.000789	.02377	51005	1.34	.0002422	.01804
55001	3.09	.000902	.02928	55005-8	3.255	.0023714	.07295
55201	3.45	.000928	.02697	55205-6	2.83	.0010373	.03688
55301	3.25	.000859	.02661	55305-8	2.27	.0017313	.07496
55901	3.05	.000930	.03052	55905-9	2.558	.0028162	.11169
56101	3.22	.000805	.02507	56105-7	2.75	.0014369	.05233
56201	3.26	.000808	.02485	56205-9	2.495	.0025326	.10169
57001	3.10	.000787	.02548	57005-7	2.706	.0013974	.05174
57101	3.35	.000958	.02860	57105	2.76	.0002527	.00916
57401	3.31	.000894	.02941	57405-8	2.49	.0019599	.07892
57501	3.30	.000785	.02381	57506-9	2.60	.0021279	.08396
58201	3.15	.000781	.02485	58206-7	2.88	.0006767	.02318
58501	3.14	.000832	.02665	58505	2.95	.0008052	.02730
58701	3.23	.000920	.02846	58705	3.01	.0003258	.01082
58901	3.05	.000723	.02379	58905	2.43	.0003292	.01355
59601	3.30	.000990	.03000	59605-6	2.14	.0007684	.03592
62801	3.14			62805	3.25	.0003938	.01212
65301	3.15			65305-8	2.925	.0024199	.08003
66001	3.46			66005-6, 8	3.25	.0017773	.05529
69301	3.12			69305	4.42	.0008767	.01984
69801	3.16			69805-6	3.74	.0016495	.04373
71901	3.02			71905	2.47	.0005531	.02239
72401	3.22			72405-6	3.155	.0019005	.05892
72601	3.17			72605-7	4.04	.0021643	.05274
72701	3.03			72705-8	2.937	.0026515	.08981
72801	3.31			72806	3.01	.0005738	.01906
72901	3.26			72905	2.48	.0003930	.01585
74301	3.13			74305	1.98	.0004054	.02047
74501	3.25			74506-8	2.78	.0014234	.05084
74601	3.17			74605-7	2.486	.0013768	.05562
76201	3.06			76205-6	3.40	.0009400	.02912
80301	3.23			80305	1.81	.0003919	.02165
81401	3.36			81405-6	2.965	.0010576	.03583
81501	3.42			81505	2.94	.0005704	.01940
84401	3.39			84405	2.48	.0005067	.02043
84901	3.10			84905-6	2.875	.0011244	.03902
85201	3.36			85205-6	2.63	.0007556	.02937
86101	3.38			86105-6	2.595	.0008522	.03244
88601	3.24			88605-9	2.566	.0026832	.11179
88901	3.14			88905-6	2.74	.0009933	.03625
92201	3.48			92205-8	2.67	.0020214	.07575
92301	3.49			92305-6	3.93	.0012908	.03223
95701	3.29			95705-7	2.58	.0013009	.05017
Average	3.239	.000875	.02700	Average	2.932	.00056037	.019189

3.5 TO 4 PER CENT PROTEID NITROGEN.

18801	3.55			18805	2.02	0.0003164	0.01567
21201	3.50			21205-12	3.567	.0054768	.15672
22201	3.65			22205-11	3.165	.0037042	.11711
25201	3.63			25205-6	2.735	.0011894	.04347
26101	3.76			26105-7	3.19	.0015273	.05113
27501	3.58			27505-9	2.688	.0028791	.10761

TABLE 25.—*Analyses showing transmission of nitrogen from one generation to another*—Continued.

3.5 TO 4 PER CENT PROTEID NITROGEN—Continued.

1902				1903			
Record number.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).	Record number.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).
33901	3.59	....	....	33905-6	2.21	0.0008932	0.04115
38001	3.82	0.000806	0.02110	38005	2.84	.0005135	.01808
38601	3.79	.001046	.02765	38605-9	3.718	.0036318	.09917
39201	3.98	.001039	.02616	39205	2.11	.0004407	.02089
39501	3.65	.001048	.02877	39506-7	2.975	.0013536	.04568
39601	3.55	.000927	.02619	39606	2.37	.0003177	.01341
42401	3.63	.001327	.02838	42405	3.07	.0006927	.02251
44501	3.57	.000796	.02531	44505	2.94	.0005187	.01764
45001	3.79	.001020	.02690	45005	3.58	.0004927	.01376
45601	3.87	.001238	.03205	45605-6	2.365	.0006777	.02995
45701	3.55	.000865	.02435	45705	4.18	.0007155	.01712
45801	3.87	.001146	.02963	45805	1.84	.0002700	.01234
48401	3.53	.000993	.02822	48405-9	2.90	.0020794	.07511
49901	3.61	.001043	.02898	49905	3.62	.0010640	.02939
55501	3.55	.001020	.02866	55506-8	2.846	.0016285	.05743
55601	3.79	.001050	.02775	55605-8	2.555	.0022356	.08822
57601	3.76	.001030	.02750	57606-8	2.37	.0015451	.06535
57801	3.80	.000891	.02353	57805	2.87	.0005207	.01814
57901	3.64	.000852	.02348	57905	3.18	.0003556	.01118
58801	3.80	.000904	.02384	58805-6	2.31	.0009317	.04048
60601	3.53	.000759	.02155	60605	1.87	.0003180	.01701
63101	3.91	....	....	63105-7	2.82	.0016570	.05951
81701	3.78	....	....	81705-10	2.27	.0031019	.13635
91301	3.57	....	....	91305	3.21	.0007197	.02242
92501	3.56	....	....	92505-7	3.32	.0017483	.05312
Average	3.68	.000990	.02650	Average	2.906	.0005508	.019204
4 TO 4.5 PER CENT PROTEID NITROGEN.							
26801	4.07	....	....	26805-8	2.825	0.0023073	0.08179
28201	4.30	....	....	28206	3.07	.0006126	.01996
46101	4.00	0.000988	0.02472	46105-7	2.69	.0014772	.05495
Average	4.123	.000988	.02472	Average	2.806	.0005496	.019588
MORE THAN 4.5 PER CENT PROTEID NITROGEN.							
50901	4.95	0.001074	0.02171	50905-6	3.435	0.0008992	0.02001
Average	....	....	....	Average	3.435	.0004496	.010005

TABLE 26.—*Summary of analyses, showing transmission of nitrogen from one generation to another.*

Range of percentage of proteid nitrogen.	1902				1903			
	Percentage of proteid nitrogen in kernels.	Number of analyses.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).	Percentage of proteid nitrogen in kernels.	Number of analyses.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).
1 to 2	1.66	15	....	....	2.59	46	0.0004960	0.01991
2 to 2.5	2.35	3	0.000601	0.02585	2.68	13	.0005172	.01915
2.5 to 3	2.61	2	....	....	2.49	11	.0005147	.02032
3 to 3.5	3.24	84	.000875	.02700	2.93	199	.0005604	.01919
3.5 to 4	3.68	31	.000990	.02650	2.91	79	.0005508	.01920
4 to 4.5	4.12	3	.000988	.02472	2.81	8	.0005496	.01959
4.5 and over	4.95	1	.001074	.02171	3.43	2	.0004496	.01000

In Table 26 the averages for each group are stated. This table is designed to show whether there has been a tendency for plants of a certain class to reproduce the qualities pertaining to that class, or whether these are lost in the offspring.

It is unfortunate that there are not a greater number of analyses of plants of medium and of low nitrogen content. The plants selected for reproduction in 1903 were largely those of high nitrogen content, and, consequently, comparatively few analyses of the low nitrogen and medium nitrogen plants of 1903 are at hand.

Table 25 shows that in the main there is a tendency for each class of plants to reproduce in the same relation to the other classes, but that there is less difference between the extreme classes in the offspring than in the parent plants. In other words, while all plants tend to reproduce their own qualities, those plants varying widely from the average produce, in general, offspring varying from the average less widely than did the parents. Although this is a rule, its application to the individual is not universal. Certain plants may be found whose tendency to variation extends through both generations. There is also wide variation between certain plants of the same parent. For instance, the plants numbered from 21205 to 21212, all of which come from the same parent, vary from 2.16 to 5.23 per cent in proteid nitrogen content, while plants 69805 and 69806 vary from 5.82 to 1.66 per cent in this constituent.[a]

It would seem, therefore, entirely reasonable to believe that a very considerable increase in the proteid nitrogen content of wheat may be effected by careful and continuous reproduction from plants of high proteid nitrogen content.

Table 27 contains the analyses of plants raised in 1902 and their progeny raised in 1903, arranged according to the number of grams of proteid nitrogen contained in the average kernel of the former.

TABLE 27.—*Analyses showing transmission of proteid nitrogen in average kernel.*

Range of proteid nitrogen in average kernel (gram).	1902				1903			
	Proteid nitrogen in average kernel (gram).	Number of analyses.	Percentage of proteid nitrogen in kernels.	Weight of average kernel (gram).	Proteid nitrogen in average kernel (gram).	Number of analyses.	Percentage of proteid nitrogen in kernels.	Weight of average kernel (gram).
0.000600 to 0.000700	0.000659	3	3.03	0.02220	0.000496	8	2.59	0.01895
0.000700 to 0.000800	.000776	9	3.29	.02405	.000444	15	2.68	.01673
0.000800 to 0.000900	.000850	18	3.33	.02576	.000544	38	2.91	.01875
0.000900 to 0.001000	.000938	18	3.37	.02796	.000514	35	2.89	.01784
0.001000 and over	.001077	15	3.71	.02880	.000593	28	3.06	.01905

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[a] Table 25 represents the properties of each plant grown in 1903 arranged according to immediate families. For instance, plants numbered 17305 17308 are all the offspring of the same plant grown in 1902. The parent bears the number 17301. This is the system of records devised by Prof. W. M. Hays, formerly of the University of Minnesota.

TABLE 28.—*Analyses showing transmission of kernel weight.*

Range of weight of average kernel (gram).	1902				1903			
	Weight of average kernel (gram).	Number of analyses.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel (gram).	Weight of average kernel (gram).	Number of analyses.	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in average kernel (gram).
Below 0.024	0.02253	12	3.61	0.000811	0.01684	19	2.69	0.000450
0.024 to 0.026	.02515	12	3.28	.000813	.01740	28	2.88	.000503
0.026 to 0.028	.02709	18	3.43	.000927	.01947	38	2.91	.000562
0.028 to 0.030	.02878	16	3.41	.000993	.01875	31	2.98	.000573
0.030 and over	.03152	6	3.31	.001044	.01869	12	2.96	.000548

Table 28 shows the analyses of plants raised in 1902 and their progeny raised in 1903, arranged according to weight of average kernel. There is more variation in this table than in the preceding one, but the tendency toward transmission of proteid nitrogen in the average kernel may be noted. The averages for 1902 are much higher than for 1903, owing partly to the higher percentage and partly to greater kernel weight.

The weight of the average kernel shows some tendency toward transmission, although there are some variations. It will be noticed that the kernels average much heavier in 1902 than in 1903, and that in spite of this the percentage of proteid nitrogen is higher in 1902. The relation of light kernel and high percentage of nitrogen does not therefore appear to hold as between crops of different years.

All of the qualities of which determinations have been made in both years appear to be transmitted. It may be safely assumed that certain plants will have greater power to transmit these qualities than will the average plant. Such plants will assert themselves in the course of three or four generations. From these plants individuals may be selected that have a combination of the desired qualities.

YIELD OF GRAIN AS AFFECTED BY SUSCEPTIBILITY TO COLD.

As has already been stated, a large number of plants on the breeding plots were killed during the winter of 1902-3. This afforded an opportunity to ascertain the effect of the severe weather upon the surviving plants. The question arose whether the surviving plants of a family of which a large percentage of members were killed yielded less per plant than the plants of a family of which but a small percentage had succumbed. As each spike of the crop of 1902 was represented by a number of plants, and as records of each plant were available, there were very extensive data at hand from which to secure information on the subject.

In Table 29 the surviving plants of each immediate family, or, in other words, the surviving plants descended from the same plant of the previous year, are classified according to the percentage of plants that survived the winter. Thus all plants of which only from 10 to 20 per cent survived are grouped together. In the next class are all plants of which from 20 to 30 per cent survived. The other classes increase by 10 per cent surviving plants until 70 per cent is reached. All plants of which more than 70 per cent survived form the last class.

Table 30 gives a summary of Table 29, the averages for each class being shown. From this table it will be seen that with an increase in the proportion of surviving plants there is an increase in the weight of grain per plant and in the number of kernels per plant. It is therefore to be concluded that decrease in yield from winter-killing is due not only to the loss of plants that are destroyed, but also to a decreased yield from most of the surviving plants.

Table 30 also shows that the weight of the average kernel is not affected by the freezing of a large proportion of the family, the decreased yield being due, it may be assumed, to the decreased number of kernels, owing to a decreased ability to tiller.

With an increase in the proportion of surviving plants there is, perhaps, a slight decrease in the percentage of proteid nitrogen in the kernels and in the number of grams of proteid nitrogen in the average kernel, although this is so slight and so irregular that it would not be safe to draw any conclusions from it. The total production of proteid nitrogen per plant naturally increases.

TABLE 29.—*Yields of plants, arranged according to percentage killed in each family.*

10 TO 20 PER CENT.

Record number for 1902.	Percentage of plants in 1903 surviving from 1902.	Weight of kernels on plant (gram).	Number of kernels.	Weight of average kernel (gram).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in kernels (gram).	Proteid nitrogen in average kernel (gram).
18801	11.1	2.1462	137	0.01567	2.02	0.04335	0.0003164
20801	10.0	14.6942	697	.02157	3.32	.48784	.0006999
25201	18.2	7.7295	363	.02173	2.73	.20732	.0005947
33301	16.7	2.9905	156	.01858	2.73	.07566	.0005066
37301	16.7	6.1394	309	.01987	2.96	.18173	.0005881
38001	14.3	2.5134	139	.01808	2.84	.07138	.0005135
39201	16.7	21.5399	1,031	.02089	2.11	.45433	.0004407
39401	16.7	9.3541	447	.02093	2.88	.21399	.0006027
40201	14.3	3.6302	194	.01871	4.69	.17026	.0008776
40401	16.7	.6316	46	.01373	3.17	.02002	.0004352
42901	16.7	1.2499	67	.01866	3.17	.03650	.0005447
43401	16.7	2.8000	124	.02258	2.92	.08176	.0006591
44501	16.7	5.9990	340	.01764	2.94	.17637	.0005187
45001	16.7	3.2340	235	.01376	3.58	.11575	.0004927
45701	14.3	.7532	44	.01712	4.18	.03148	.0007155
45801	16.7	1.5298	124	.01234	1.84	.02815	.0002700
49501	14.3	1.2716	67	.01898	3.24	.04120	.0006149
49901	14.3	.6760	23	.02939	3.62	.02136	.0010640
51001	16.7	15.5835	862	.01804	1.34	.20881	.0002422
57101	16.7	3.7263	407	.00916	2.76	.10285	.0002527
58501	16.7	7.4516	273	.02730	2.95	.21982	.0008052
58701	16.7	2.5436	235	.01082	3.01	.07656	.0003258
58901	16.7	2.3031	170	.01355	2.43	.05596	.0003292
60601	16.7	.5952	35	.01701	1.87	.01113	.0003180
62801	16.7	1.3451	111	.01212	3.25	.04272	.0003938
69301	16.7	2.0430	103	.01984	4.42	.09030	.0008767
74301	16.7	4.4222	216	.02047	1.98	.08756	.0004051
84401	16.7	8.7448	428	.02043	2.48	.21687	.0005067
91301	14.3	3.0940	138	.02242	3.21	.09932	.0007197
94101	14.3	.5595	22	.02543	2.67	.01494	.0006790
Average	15.78	4.7098	251.4	.01856	2.91	.12294	.00051366

TABLE 29.—*Yields of plants, arranged according to percentage killed in each family*—Cont'd.

20 TO 30 PER CENT.

Record number for 1902.	Percentage of plants in 1903 surviving from 1902.	Weight of kernels on plant (gram).	Number of kernels.	Weight of average kernel (gram).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in kernels (gram).	Proteid nitrogen in average kernel (gram).
18901	20.0	1.2046	84	0.01431	3.64	0.04437	0.0005219
27001	20.0	16.4120	866	.01895	2.63	.43164	.0004984
34601	28.6	6.1962	280	.02213	3.12	.19332	.0006904
36901	20.0	5.0200	267	.01880	3.88	.19478	.0007295
39601	28.6	4.6383	346	.01341	2.37	.10967	.0003177
40301	25.0	3.6003	179	.02011	3.11	.11197	.0006255
40501	20.0	4.1546	170	.02444	2.82	.11716	.0006892
42201	25.0	1.0827	59	.01615	2.54	.03587	.0004494
42401	20.0	1.4892	66	.02251	3.07	.04572	.0006927
43501	25.0	1.4464	93	.01555	4.13	.05974	.0006423
48701	28.6	5.2800	321	.01643	3.06	.16124	.0005038
48801	25.0	9.8346	547	.01798	2.70	.26553	.0004877
57801	20.0	4.8988	270	.01814	2.87	.14060	.0005207
57901	25.0	2.4731	221	.01118	3.18	.07859	.0003556
58801	28.6	12.5470	626	.02024	2.31	.33541	.0004658
71901	20.0	28.2136	1,260	.02239	2.47	.69688	.0005531
80301	20.0	15.7835	729	.02165	1.81	.28569	.0003919
81501	20.0	2.8327	146	.01940	2.94	.08328	.0005704
91901	22.2	3.4961	199	.01756	3.09	.10771	.0005415
94601	28.6	6.2877	106	.04425	1.87	.11373	.0008062
Average	23.5	6.84457	341.75	.019779	2.88	.18065	.0005527

30 TO 40 PER CENT.

26101	33.3	1.9790	122	0.01704	3.19	0.06318	0.0005091
28201	33.3	4.3698	219	.01996	3.07	.13415	.0006126
28801	33.3	8.3240	386	.02311	2.96	.25019	.0006842
33901	33.3	6.7169	313	.02057	2.21	.12186	.0004466
37901	33.3	.5757	28	.01820	2.48	.01447	.0004556
38501	37.5	5.03306	252	.01814	3.25	.24284	.0006738
38701	33.3	7.2545	365	.01988	2.59	.18789	.0005148
48301	33.3	7.3424	315	.02117	3.08	.21633	.0006433
50901	33.3	2.0631	167	.01000	3.43	.07041	.0004496
59601	33.3	8.4456	474	.01796	2.14	.18039	.0003842
69701	33.3	3.7810	244	.01550	2.50	.09453	.0003874
88901	33.3	7.6051	419	.01812	2.74	.20632	.0004966
92301	33.3	4.1975	253	.01611	3.93	.18308	.0006454
Average	33.6	5.2065	273.6	.01813	2.89	.15125	.0005310

40 TO 50 PER CENT.

17501	42.9	1.1495	55	0.01865	4.01	0.04268	0.0007259
21301	44.4	4.6950	259	.01819	3.01	.14144	.0005449
33101	42.9	2.9905	156	.01858	2.73	.07566	.0005066
44601	42.9	1.8251	93	.01963	2.73	.04998	.0005390
50701	40.0	.5329	32	.01664	3.17	.01712	.0005396
72401	40.0	8.3672	321	.02946	3.15	.26913	.0009502
72801	40.0	2.0970	110	.01906	3.01	.06312	.0005738
72901	40.0	2.6462	167	.01585	2.48	.06563	.0003930
76201	40.0	6.9409	472	.01456	3.40	.22024	.0004700
81401	40.0	2.9064	156	.01791	2.96	.07905	.0005288
86101	40.0	5.3261	314	.01622	2.59	.14008	.0004261
92201	44.4	4.1705	238	.01894	2.67	.11199	.0005053
92501	42.9	5.4034	297	.01771	3.32	.16649	.0005828
94401	42.9	8.6610	484	.01769	2.27	.20040	.0004046
Average	41.7	4.1223	225.3	.01843	2.96	.11736	.0005493

TABLE 29.—*Yields of plants, arranged according to percentage killed in each family*—Cont'd.

50 TO 60 PER CENT.

Record number for 1902.	Percentage of plants in 1903 surviving from 1902.	Weight of kernels on plant (gram).	Number of kernels.	Weight of average kernel (gram).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in kernels (gram).	Proteid nitrogen in average kernel (gram).
17301	50.0	3.0000	156	0.01980	3.21	0.09556	0.0006380
17401	54.5	11.7777	581	.01961	2.65	.30061	.0005161
20701	50.0	6.6626	327	.02012	2.85	.18906	.0005697
27201	50.0	12.9727	611	.02105	2.56	.31569	.0005371
33401	50.0	5.2333	271	.01818	1.98	.10621	0003569
33601	50.0	6.0463	273	.02205	2.61	.14759	.0005729
34201	57.1	6.8220	328	.02019	2.86	.18949	.0005769
37701	50.0	4.1993	237	.01946	2.64	.12164	.0005130
39501	50.0	1.9040	89	.02284	2.97	.05663	.0006768
45601	50.0	2.3719	140	.01497	2.36	.04852	.0003388
46101	50.0	4.8728	273	.01832	2.69	.13084	.0004924
55201	50.0	6.0242	309	.01844	2.83	.15608	.0005186
57601	57.1	9.3804	435	.02178	2.37	.18680	.0005150
63101	50.0	4.7193	224	.01984	2.82	.12281	.0005523
69801	50.0	7.2278	334	.02186	3.74	.17078	.0008247
85201	50.0	4.2040	295	.01468	2.63	.11078	.0003778
88601	57.1	5.6295	266	.02236	2.57	.14178	.0005366
Average	51.5	6.0616	302.9	.01974	2.73	.15237	.0005361

60 TO 70 PER CENT.

Record number for 1902.	Percentage of plants in 1903 surviving from 1902.	Weight of kernels on plant (gram).	Number of kernels.	Weight of average kernel (gram).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in kernels (gram).	Proteid nitrogen in average kernel (gram).
21201	66.7	2.5064	137	0.01956	3.57	0.09431	0.0006846
32201	60.0	5.8304	288	.01937	2.64	.11603	.0005027
32601	66.7	2.9653	166	.01890	2.62	.05309	.0006177
48101	66.7	11.6655	608	.01919	2.38	.27765	.0004567
48501	66.7	6.0446	341	.01813	3.06	.18124	.0005437
55001	66.7	8.6833	476	.01824	3.25	.25347	.0005928
55301	66.7	5.4606	280	.01874	2.27	.12536	.0004328
55501	66.7	10.4714	529	.01914	2.85	.29155	.0005428
57001	60.0	5.0125	319	.01725	2.71	.13688	.0004658
57301	66.7	7.7761	443	.01752	2.54	.20018	.0004588
57401	66.7	7.6312	383	.01973	2.49	.19910	.0004900
57501	66.7	8.1116	382	.02099	2.60	.20327	.0005320
63501	60.0	4.1723	229	.01791	2.17	.06748	.0003749
66001	66.7	5.9586	309	.01919	3.25	.17590	.0005924
72601	60.0	4.6412	265	.01758	4.04	.14328	.0007214
72701	66.7	9.3629	396	.02245	2.94	.28276	.0006629
73301	66.7	7.7977	354	.02194	2.59	.21334	.0005639
74601	60.0	8.3679	451	.01854	2.49	.20681	.0004589
84901	66.7	4.1284	209	.01951	2.87	.13763	.0005622
92901	62.5	4.6848	258	.01763	2.81	.12877	.0004908
95701	60.0	5.4211	318	.01672	2.58	.14079	.0004336
Average	64.6	6.5092	340	.01896	2.80	.17280	.0005324

70 PER CENT AND OVER.

Record number for 1902.	Percentage of plants in 1903 surviving from 1902.	Weight of kernels on plant (gram).	Number of kernels.	Weight of average kernel (gram).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen in kernels (gram).	Proteid nitrogen in average kernel (gram).
21701	87.5	9.75524	447	0.02157	2.78	0.30200	0.0006049
21801	80.0	11.5721	622	.01963	3.13	.35575	.0006057
21901	88.9	8.3406	398	.02114	3.53	.30995	.0007501
22201	87.5	4.0677	229	.01674	3.16	.12604	.0005292
26801	80.0	7.1981	329	.02045	2.82	.20306	.0005768
26901	71.4	3.8910	206	.01871	2.77	.10870	.0005189
27301	80.0	6.6162	343	.01913	2.93	.18438	.0005447
27501	71.4	6.8618	310	.02152	2.69	.17267	.0005758
38601	71.4	3.9532	186	.01983	3.72	.11558	.0007294
48401	83.3	4.4668	277	.01502	2.90	.10033	.0004159
55601	83.3	10.2785	435	.02211	2.55	.29008	.0006669
55901	83.3	10.9242	489	.02234	2.56	.27788	.0005682
56101	75.0	10.7383	617	.01744	2.75	.29783	.0004790
56201	83.3	11.2241	563	.02034	2.49	.27997	.0005065
58201	75.0	2.8084	227	.01159	2.88	.08385	0003383
65301	83.3	7.5858	394	.02001	2.92	.18248	.0006050
74501	100.0	3.4799	191	.01695	2.78	.10355	.0004745
81701	100.0	12.7593	569	.02272	2.27	.29500	.0005170
92401	71.4	4.4131	234	.01822	2.63	.12426	.0004826
94201	83.3	5.9603	339	.01748	2.58	.16548	.0004426
94901	75.0	7.0172	388	.01780	2.85	.21294	.0005072
95501	100.0	7.2956	374	.01767	2.50	.18689	.0004418
Average	82.4	7.3275	371.2	.01902	2.83	.20357	.0005348

TABLE 30.—*Summary of yields of plants, arranged according to percentage killed in each family.*

Percentage of plants grouped according to survivors of 1903 from 1902.	Number of analyses.	Percentage of plants in 1903 surviving from 1902.	Weight of kernels on plant (grams).	Number of kernels per plant.	Weight of average kernel (gram).	Percentage of proteid nitrogen in kernels.	Proteid nitrogen (gram) in	
							Kernels.	Average kernel.
10 to 20	30	15.8	4.7098	251	0.01856	2.91	0.12294	0.0005437
20 to 30	20	23.5	6.8446	342	.01978	2.88	.18065	.0005527
30 to 40	13	33.6	5.2065	274	.01813	2.89	.15125	.0005310
40 to 50	14	41.7	4.1223	225	.01843	2.96	.11736	.0005493
50 to 60	17	51.5	6.0616	303	.01974	2.73	.15237	.0005361
60 to 70	21	64.6	6.5092	340	.01896	2.80	.17280	.0005324
70 and over	22	82.4	7.3275	371	.01902	2.83	.20357	.0005348

YIELD AND NITROGEN CONTENT OF GRAIN AS AFFECTED BY LENGTH OF GROWING PERIOD.

Early-maturing varieties of wheat are, in general, better yielding sorts in Nebraska than are later maturing ones. There are some exceptions to this rule, however, Turkish Red yielding better than any earlier maturing variety. The advantages from early maturity have usually been ascribed to the cooler weather and greater supply of moisture that obtain in the early summer. The hot, dry weather common in July is thought to prevent the filling out of the kernel and to cause light yield and light volume weight.

Each wheat plant on the breeding plots was harvested separately in 1903, and a record was kept of the date of harvesting of each of these plants. These data have been tabulated for the purpose of showing the relation between the length of the growing season and the yield of grain from individual plants of the same variety.

Table 31 contains these data, tabulated according to the date of ripening. Plants ripening between the 7th and 11th of July, 1903, form the first class, those ripening between July 11 and 15 the second class, and the succeeding classes increase by four days until July 27, all ripening after that date constituting the last class. The dates of ripening thus extend over a period of three weeks.

The season of 1903 was a very wet and cool one. The effect of this upon the wheat crop is shown by the fact that the crop in the field was not ready to harvest until July 10, while usually it is harvested between the 20th and 30th of June. Even at the close of the ripening period the weather did not become dry or hot as compared with the normal season. It will therefore be seen that the ordinary advantages from early maturity did not obtain, or at least not in the customary way. It may also be said that some of the later maturing wheats yielded as well in 1904 as did the Turkish Red.

Table 32 is a summary of Table 31, with a statement of the average for each class.

Table 33 is a summary of the same plants, tabulated according to the yield of grain per plant.

Table 34 is a summary of the same plants, tabulated according to the percentage of proteid nitrogen.

It is very evident from these tables that the early-maturing plants are the most prolific. The weight of the average kernel remains very uniform, so that the later maturing plants do not appear to have produced shrunken kernels. Evidently the plants ripening during the first four days produced the largest amounts of grain, and their kernels were as heavy as those produced later. The smaller productiveness of the later maturing plants in the season of 1903 does not appear to have been due to a shrunken or light kernel.

The percentage of proteid nitrogen appears to be somewhat less in the grain of the early-maturing plants. The number of grams of proteid nitrogen in the average kernel is likewise less in these early-maturing plants.

The relation of length of growing season to both yield and composition of grain is contrary to what might have been supposed. A long growing period without excessively hot or dry weather might naturally be thought to increase the yield and increase the percentage of carbohydrates in the grain.

The season of 1904 was very similar to that of 1903 up to time of wheat harvest. The data for 1904, when tabulated, will serve as a check on the results obtained in 1903.

TABLE 31.—*Yield and nitrogen content of grain, tabulated according to length of growing period.*

DATES RIPE: JULY 7 TO 11, 1903.

Record number.	Date ripe.	Yield (grams).	Percentage of proteid nitrogen.	Weight of average kernel (gram).	Proteid nitrogen (gram) in—	
					Kernels.	Average kernel.
21805	July 10	20.9290	2.69	0.01699	0.56299	0.0004569
21806	....do...	14.2450	2.71	.02378	.38604	.0006444
21807	....do...	9.4172	2.73	.02498	.25709	.0006664
21808	....do...	19.7446	2.57	.01708	.50744	.0004389
21809	....do...	8.0214	2.73	.01919	.21898	.0005238
21810	....do...	1.0304	2.69	.019816	.02772	.0005330
21811	....do...	11.9114	3.75	.021007	.44666	.0007877
21812	....do...	14.8139	4.26	.01507	.63107	.0006420
21813	....do...	4.0258	4.01	.01877	.16377	.0007582
55506	July 8	17.8506	2.80	.02062	.49995	.0005773
55507	....do...	9.8228	2.63	.01949	.25834	.0005126
55605	....do...	10.9180	2.64	.02184	.28823	.0005765
55606	....do...	11.0930	2.58	.02205	.28580	.0005690
55607	....do...	2.3931	2.69	.01734	.06437	.0004665
55608	....do...	22.5848	2.31	.02699	.52194	.0006236
55905	....do...	5.7948	2.67	.01751	.15470	.0004674
55906	July 7	7.9968	2.81	.01603	.22471	.0004503
55907	July 8	19.3966	2.59	.02590	.50238	.0006707
55908	....do...	12.1221	2.42	.02175	.29575	.0005262
55909	July 9	9.2120	2.30	.03050	.21187	.0007016
56106	July 8	12.0161	2.57	.01866	.30881	.0004795
56107	July 7	14.4556	2.96	.01658	.42790	.0004907
56206	July 8	9.3093	2.42	.01829	.22529	.0004426
56207	....do...	10.9073	2.34	.02361	.25522	.0005524
56208	....do...	13.5720	2.61	.02356	.34616	.0006149
56209	....do...	15.8086	2.59	.01664	.40945	.0004310
81505	July 10	2.8327	2.94	.01940	.08328	.0005704
81706	July 8	15.3928	2.71	.02132	.41715	.0005778
81707	....do...	18.3614	2.34	.02336	.42965	.0005466
81708	....do...	7.3993	2.41	.02578	.17833	.0006213
81709	....do...	16.4692	2.28	.02175	.37548	.0004960

TABLE 31.—*Yield and nitrogen content of grain, tabulated according to length of growing period*—Continued.

DATES RIPE: JULY 7 TO 11, 1903—Continued.

Record number.	Date ripe.	Yield (grams).	Percentage of proteid nitrogen.	Weight of average kernel (gram).	Proteid nitrogen (gram) in—	
					Kernels.	Average kernel.
81710	July 8	9.1411	1.92	0.02308	0.17550	0.0004432
88605	July 10	1.6362	2.80	.02731	.04581	.0007640
88606	....do...	9.9456	2.53	.02068	.25162	.0005231
88607	....do...	5.1584	2.61	.02205	.13463	.0005754
88608	....do...	1.5355	2.47	.02075	.03793	.0005125
88609	....do...	9.8719	2.42	.02100	.23890	.0005082
94907	....do...	12.1918	2.94	.01948	.35844	.0005726
94908	....do...	2.3678	1.96	.01894	.04641	.0003713
94909	July 9	3.6977	3.60	.01696	.13312	.0006106
95505	....do...	.3146	2.81	.00850	.00884	.0002389
95506	....do...	11.0548	2.74	.01852	.30291	.0005074
95507	....do...	12.1592	2.59	.02029	.31492	.0005515
95508	....do...	14.4617	2.56	.01954	.37023	.0005003
95509	....do...	2.9475	2.48	.02136	.07310	.0005297
95510	....do...	2.8356	1.81	.01783	.05132	.0003228
95705	July 10	10.3426	2.54	.01626	.26270	.0004131
95706	....do...	5.1629	2.73	.01934	.14095	.0005279
95707	....do...	.7577	2.47	.01457	.01872	.0003599
Average...	July 8.9	9.9067	2.69	.02024	.26475	.0005356

DATES RIPE: JULY 11 TO 15, 1903.

21905	July 13	14.3111	2.64	0.01809	0.37781	0.0004777
21906	....do...	10.4800	3.18	.02563	.33403	.0008168
21907	....do...	2.9248	3.35	.01851	.09798	.0006201
21908	....do...	3.5574	3.82	.02056	.13589	.0007855
21909	....do...	12.1819	4.43	.02317	.53889	.0010265
21911	....do...	8.4593	5.48	.02209	.46356	.0012103
21912	....do...	9.7236	2.31	.01907	.22461	.0004404
21913	....do...	10.1925	3.01	.02072	.30680	.0006235
22205	....do...	2.6965	2.81	.00953	.07577	.0002677
22210	....do...	6.0173	3.17	.02019	.19075	.0006401
22211	....do...	11.5675	3.17	.02062	.36671	.0006537
27005	....do...	16.4120	2.63	.01895	.43164	.0004984
27205	....do...	16.4061	2.41	.01841	.39539	.0004437
27206	....do...	19.1854	2.36	.02469	.45276	.0005827
27207	....do...	3.3266	2.92	.02004	.09712	.0005850
27305	....do...	5.5666	2.58	.02085	.14362	.0005379
27306	....do...	13.3011	3.47	.01945	.32853	.0004803
27307	....do...	3.0850	2.53	.01847	.07805	.0004674
27308	....do...	4.5123	4.15	.01777	.18726	.0007373
27505	....do...	12.0399	2.12	.02183	.24942	.0004627
27506	....do...	10.0005	2.70	.02252	.27003	.0006082
27508	....do...	5.5324	2.64	.02287	.14608	.0006037
48406	....do...	3.2964	4.87	.01324	.16053	.0006447
48407	....do...	11.2890	1.50	.01572	.16933	.0002358
48408	....do...	.3485	2.81	.01291	.00979	.0003627
48409	....do...	6.4302	2.02	.02048	.12989	.0004137
48506	....do...	9.4585	3.20	.01701	.30267	.0005444
48507	....do...	1.6036	2.64	.02296	.04233	.0006062
48508	....do...	11.2008	2.76	.01858	.30986	.0005127
48806	....do...	9.8346	2.70	.01798	.26553	.0004877
55005	....do...	7.9684	3.05	.02028	.24303	.0006185
55006	....do...	7.1852	3.16	.01593	.22705	.0005034
55305	....do...	2.5160	2.48	.01507	.06240	.0003736
55306	....do...	4.1323	2.18	.01931	.09008	.0004210
55307	....do...	5.6864	1.89	.01663	.10747	.0003142
55308	....do...	9.5078	2.54	.02395	.24150	.0006225
56105	....do...	5.7431	2.73	.01709	.15679	.0004667
56205	....do...	6.5232	2.51	.01959	.16373	.0004917
57005	....do...	1.5364	2.71	.01746	.04164	.0004731
57006	....do...	10.1836	2.76	.01453	.28107	.0004010
57007	....do...	3.3176	2.65	.01975	.08792	.0005233
57105	....do...	3.7263	2.76	.00916	.10285	.0002527
57305	....do...	8.5777	3.19	.01666	.29188	.0005826
57306	....do...	7.9772	2.86	.01838	.22815	.0005257
57307	....do...	4.7117	2.43	.01801	.11445	.0004387
57308	....do...	9.8378	1.69	.01705	.16626	.0002881
57405	....do...	.8328	1.98	.02031	.01649	.0004022
57406	....do...	2.4923	2.75	.01846	.06854	.0005077
57407	....do...	14.9992	2.62	.01968	.39297	.0005157

TABLE 31.—*Yield and nitrogen content of grain, tabulated according to length of growing period*—Continued.

DATES RIPE: JULY 11 TO 15, 1903—Continued.

Record number.	Date ripe.	Yield (grams).	Percentage of proteid nitrogen.	Weight of average kernel (gram).	Proteid nitrogen (gram) in— Kernels.	Proteid nitrogen (gram) in— Average kernel.
57408	July 13	12.2004	2.61	0.02047	0.31842	0.0005343
57506	do	2.7616	2.80	.01534	.07733	.0004296
57507	do	6.9861	2.85	.01946	.19905	.0005545
57508	do	12.0728	2.21	.03177	.26680	.0007021
57509	do	10.6261	2.54	.01739	.26990	.0004417
57606	do	3.0790	2.74	.02333	.08436	.0006391
57607	do	16.4433	1.73	.02234	.24847	.0003865
57608	do	8.6189	2.64	.01968	.22756	.0005195
58206	do	1.3961	2.67	.00943	.03728	.0002519
58207	do	4.2207	3.09	.01375	.13042	.0004248
65305	do	1.8018	4.92	.02310	.08865	.0011365
65306	do	9.8298	2.41	.01807	.23690	.0004355
65307	do	7.0051	2.28	.01878	.15971	.0004282
65308	do	11.7006	2.09	.02008	.24468	.0004197
94905	July 11	4.4423	2.35	.01553	.10439	.0003650
94906	do	12.3862	3.41	.01808	.42236	.0006166
Average	July 13	7.6611	2.81	.01887	.20820	.0005290

DATES RIPE: JULY 15 TO 19, 1903.

18906	July 15	0.9229	3.48	0.01420	0.03212	0.0004941
21706	do	19.3318	4.71	.02390	.91052	.0011283
21707	do	12.3685	2.19	.02125	.27086	.0004654
26105	do	1.8242	3.02	.01393	.05508	.0003662
33406	July 18	4.6045	2.87	.01627	.13215	.0004670
34206	do	1.5940	3.73	.01968	.05946	.0007340
34208	do	2.9886	2.13	.01916	.06366	.0004081
37906	July 15	.2062	2.44	.01086	.00503	.0002649
45005	do	3.2340	3.58	.01376	.11575	.0004927
45605	do	.7081	2.82	.01161	.01997	.0003273
48405	do	.9701	3.31	.01276	.03211	.0004225
48505	do	1.9154	3.66	.01398	.07010	.0005117
51005	do	15.5835	1.34	.01804	.20881	.0002422
63105	July 18	1.5452	3.24	.01717	.05007	.0005563
63106	do	3.3006	2.79	.02001	.09208	.0005581
66006	do	6.0090	3.54	.01642	.21272	.0005812
72605	do	1.1166	4.65	.01718	.05192	.0007988
72806	do	2.0970	3.01	.01906	.06312	.0005738
74605	do	7.1181	2.60	.01784	.18507	.0004638
81705	do	9.7922	1.98	.02106	.19388	.0004170
88905	July 16	5.3069	2.83	.01811	.15019	.0005126
88906	do	9.9034	2.65	.01814	.26245	.0004807
91905	do	3.4436	3.36	.01739	.11570	.0005844
91906	do	3.5486	2.81	.01774	.09972	.0004986
92205	do	5.2616	2.74	.01525	.14417	.0004179
92206	do	1.1074	2.67	.02407	.02957	.0006428
92207	do	3.6926	2.55	.01767	.09416	.0004505
92208	do	6.6206	2.72	.01876	.18008	.0005102
92305	do	2.3859	2.93	.01491	.06991	.0004369
92306	do	6.0091	4.93	.01732	.29625	.0008539
92406	do	8.2366	3.11	.02168	.25616	.0006741
92407	do	.8983	1.66	.01695	.01491	.0002814
92408	do	3.7820	2.97	.01827	.11233	.0005426
92409	do	5.7131	2.30	.01814	.13140	.0004171
92506	do	3.8709	4.39	.01690	.16993	.0007421
92507	do	9.6779	2.58	.01916	.24969	.0004944
92905	do	2.7000	3.50	.01534	.09450	.0005369
92906	do	2.8816	2.99	.01592	.08616	.0004760
92907	do	4.4673	2.56	.02040	.11436	.0005220
92908	do	3.2388	2.32	.01732	.07514	.0004018
92909	do	10.1363	2.70	.01916	.27367	.0005173
94105	July 15	.5595	2.67	.02543	.01494	.0006790
94205	July 16	1.2117	1.65	.01893	.01999	.0003124
94206	do	7.5006	2.78	.01866	.20851	.0005187
94207	do	13.7057	2.86	.01909	.39199	.0005460
94208	do	3.7828	3.10	.01175	.11727	.0003642
94406	do	10.5556	2.47	.01923	.26073	.0004749
94407	do	6.7664	2.07	.01615	.14007	.0003343
94605	do	.7319	1.95	.01307	.01427	.0002549
94606	do	11.8435	1.80	.07544	.21319	.0013576
Average	July 16.2	5.1354	2.87	.01869	.14452	.0005222

TABLE 31.—*Yield and nitrogen content of grain, tabulated according to length of growing period*—Continued.

DATES RIPE: JULY 19 TO 23, 1903.

Record number.	Date ripe.	Yield (grams).	Percentage of proteid nitrogen.	Weight of average kernel (gram).	Proteid nitrogen (gram) in—	
					Kernels.	Average kernel.
17409	July 21	14.8957	2.75	0.01857	0.40964	0.0005108
17505	July 20	.3885	4.70	.01340	.01826	.0006296
18805	July 21	2.1462	2.02	.01567	.04335	.0003164
20707	...do...	9.9070	2.77	.02282	.27443	.0006181
20708	July 20	2.4690	2.58	.02024	.06399	.0005221
21211	July 21	.2806	3.15	.02806	.00884	.0008839
21306	July 20	4.1516	2.90	.01837	.12039	.0005327
21308	...do...	5.8080	3.45	.01641	.20038	.0005660
21710	July 21	.8478	2.59	.01437	.02196	.0003722
21711	...do...	17.1820	2.71	.01968	.46563	.0005334
22209	...do...	.4336	3.84	.01399	.01665	.0005371
26806	July 20	2.7255	2.60	.01793	.07086	.0004662
26807	...do...	17.2324	2.80	.02390	.48250	.0006692
26808	...do...	3.8811	3.09	.01748	.11992	.0005402
26906	July 22	4.2376	2.71	.01859	.11484	.0005037
26907	July 20	1.8276	2.61	.01792	.04995	.0004677
26909	...do...	2.9999	2.80	.01667	.08400	.0004667
32606	July 22	2.0162	2.88	.02145	.05807	.0006177
33105	July 21	2.5601	2.91	.01939	.07450	.0005644
33905	...do...	11.1476	1.61	.02194	.17948	.0003533
33906	...do...	2.2862	2.81	.01921	.06424	.0005399
38606	...do...	8.4605	2.63	.02110	.22251	.0005549
38607	...do...	.3037	4.55	.01598	.01382	.0007273
38608	...do...	3.0228	2.82	.01913	.08522	.0005394
38609	...do...	6.7665	2.74	.02319	.18540	.0006475
38706	July 20	7.2545	2.59	.01988	.18789	.0005148
40405	July 21	.6316	3.17	.01373	.02002	.0004352
42206	...do...	.3161	1.46	.01264	.00462	.0001846
44607	July 20	1.8246	2.44	.01806	.04452	.0004408
48106	July 21	11.6655	2.38	.01919	.27765	.0004567
48305	July 20	12.0278	2.87	.02543	.34524	.0007299
48306	...do...	2.6571	3.29	.01692	.08742	.0005568
48706	...do...	6.1989	3.00	.01635	.18596	.0004906
55007	...do...	2.1571	4.21	.01828	.09082	.0007696
55008	July 21	17.4226	2.60	.01846	.45299	.0004799
55206	...do...	11.3592	2.56	.01965	.29079	.0005031
58805	July 20	23.1471	2.74	.01999	.63422	.0005464
59606	...do...	9.7084	2.16	.01712	.20970	.0003698
63107	...do...	9.3120	2.43	.02233	.22628	.0005426
63505	July 21	4.0230	1.90	.01934	.07644	.0003674
66008	July 20	3.1555	3.59	.01814	.11328	.0006510
69305	...do...	2.0430	4.42	.01984	.09030	.0008767
71905	...do...	28.2136	2.47	.02239	.69688	.0005531
72606	...do...	9.3629	1.89	.01724	.18538	.0003414
72607	...do...	3.4442	5.59	.01832	.19253	.0010241
72705	...do...	9.1522	2.13	.02191	.19936	.0004668
72706	...do...	14.6802	3.86	.02484	.56666	.0009588
72707	July 21	4.5806	3.49	.02036	.15986	.0007105
72708	July 20	9.0386	2.27	.02270	.20518	.0005154
74507	July 21	9.2130	3.02	.01869	.27823	.0005644
76206	July 20	5.4411	4.45	.01217	.24213	.0005417
84905	...do...	.7130	2.32	.01927	.01654	.0004471
84906	...do...	7.5438	3.43	.01975	.25873	.0006773
85206	July 21	4.9315	2.66	.01312	.13118	.0003332
92405	...do...	3.4356	3.10	.01605	.10650	.0004977
94209	...do...	3.6006	2.49	.01895	.08965	.0004719
Average	July 20.1	6.5399	2.93	.01886	.18064	.0005482

DATES RIPE: JULY 23 TO 27, 1903.

17305	July 23	3.6302	3.03	0.01984	0.10999	0.0006010
17306	...do...	3.9968	3.09	.01645	.12350	.0005082
17308	...do...	1.2275	3.25	.02012	.03994	.0006540
17406	...do...	2.0907	3.29	.01686	.06878	.0005547
17408	...do...	9.2038	2.18	.01852	.20065	.0004037
17410	...do...	16.9987	2.88	.02285	.48957	.0006580
20705	...do...	1.8517	3.09	.01698	.05722	.0005249
20706	...do...	3.3138	2.78	.02033	.09212	.0005652
20710	...do...	17.1115	2.83	.01974	.48428	.0005586
20805	...do...	14.6942	3.32	.02157	.48784	.0006999

TABLE 31.—*Yield and nitrogen content of grain, tabulated according to length of growing period*—Continued.

DATES RIPE: JULY 23 TO 27, 1903—Continued.

Record number.	Date ripe.	Yield (grams).	Percentage of protein nitrogen.	Weight of average kernel (gram).	Protein nitrogen (gram) in—	
					Kernels.	Average kernel.
21307	July 24	2.5691	3.04	0.01796	0.07810	0.0005461
21705	July 23	1.5420	2.45	.02659	.03778	.0006514
21708	....do...	9.2850	2.33	.02381	.21634	.0005547
21709	....do...	7.7296	2.47	.02141	.19092	.0005289
22206	....do...	2.5712	3.22	.01720	.08086	.0005538
22208	....do...	1.9090	3.18	.01619	.06071	.0005144
26905	July 24	6.4102	2.76	.01966	.17692	.0005427
26908	....do...	3.9797	2.96	.02073	.11780	.0006135
27507	July 23	1.3746	3.08	.01833	.04234	.0005646
27509	....do...	5.3615	2.90	.02206	.15549	.0006399
28805	....do...	2.1851	2.91	.02512	.04359	.0007309
28806	....do...	14.4630	3.02	.02111	.43679	.0006376
33106	....do...	.3089	2.94	.01716	.00908	.0005045
33107	....do...	6.1026	2.35	.01919	.14341	.0004510
33405	....do...	8.1268	2.03	.01930	.16498	.0003919
34205	....do...	9.1498	2.73	.01972	.24979	.0005383
34207	....do...	13.5556	2.84	.02219	.38505	.0006273
38506	July 24	1.6799	2.89	.01975	.04855	.0005712
38605	July 23	1.2124	5.85	.01987	.07093	.0011627
40205	....do...	3.6302	4.69	.01871	.17026	.0008776
40305	....do...	3.6003	3.11	.02011	.11197	.0006255
42905	....do...	1.2499	3.17	.01866	.03650	.0005447
44505	....do...	5.9990	2.94	.01764	.17637	.0005187
44606	....do...	2.5235	2.90	.02035	.07318	.0005902
45606	....do...	4.0358	1.91	.01834	.07708	.0003504
45705	....do...	.7532	4.18	.01712	.03148	.0007155
45805	....do...	1.5298	1.84	.01234	.02815	.0002700
46107	....do...	8.3935	2.54	.01756	.21319	.0004460
50705	....do...	.5958	3.54	.01986	.02109	.0007032
50706	....do...	.4701	2.80	.01343	.01316	.0003761
50905	....do...	2.3982	3.30	.01085	.07914	.0003581
55205	July 24	.6893	3.10	.01723	.02137	.0005342
57805	....do...	4.8988	2.87	.01814	.14060	.0005207
57905	....do...	2.4731	3.18	.01118	.07859	.0003556
58505	July 23	7.4516	2.95	.02730	.21982	.0008052
58705	....do...	2.5436	3.01	.01082	.07656	.0003258
60605	....do...	.5952	1.87	.01701	.01113	.0003180
62805	....do...	1.3451	3.25	.01212	.04272	.0003938
74606	....do...	9.6451	2.30	.02079	.22184	.0004781
74607	....do...	8.3406	2.56	.01699	.21352	.0004349
91305	July 24	3.0940	3.21	.02242	.09932	.0007197
92505	....do...	2.6615	3.00	.01706	.07985	.0005118
Average	July 23.2	4.9015	2.93	.01878	.13654	.0005544

DATES RIPE: JULY 27, 1903, OR LATER.

17307	July 27	3.1454	3.46	0.02279	0.10883	0.0007886
17405	....do...	15.6996	2.13	.02127	.33441	.0004531
17506	....do...	2.2881	3.52	.02460	.08044	.0008660
17507	....do...	.7720	3.80	.01795	.02934	.0006822
18905	....do...	1.4864	3.81	.01443	.05663	.0005498
20709	....do...	5.3229	3.05	.02063	.16235	.0006292
21205	....do...	2.3642	3.16	.01922	.07471	.0006074
21206	....do...	2.8564	5.23	.01917	.14939	.0010026
21207	....do...	2.3066	2.96	.01955	.06804	.0005766
21208	....do...	5.1594	3.24	.01798	.16712	.0005824
21209	....do...	1.4484	3.61	.01627	.05228	.0005875
21210	....do...	3.9143	5.03	.01577	.19689	.0007934
21212	....do...	1.7216	2.16	.02049	.03718	.0004427
21305	....do...	6.2514	2.67	.020037	.16691	.0005350
22207	....do...	3.2787	2.77	.01940	.09082	.0005374
25205	....do...	10.7836	2.71	.02066	.28560	.0005599
25206	....do...	4.6754	2.76	.02281	.12904	.0006295
26106	....do...	2.0737	2.63	.02304	.05454	.0006060
26107	....do...	2.0390	3.92	.01416	.07993	.0005551
26805	....do...	4.9456	2.81	.02248	.13897	.0006317
28206	....do...	4.3698	3.07	.01996	.13415	.0006126
32206	....do...	10.4036	1.81	.02052	.18831	.0003714
32207	....do...	1.2573	3.48	.01822	.04375	.0006341
32605	....do...	5.2268	1.20	.02323	.06272	.0002788

TABLE 31.—*Yield and nitrogen content of grain, tabulated according to length of growing period*—Continued.

DATES RIPE: JULY 27, 1903, OR LATER—Continued.

Record number.	Date ripe.	Yield (grams).	Percentage of proteid nitrogen.	Weight of average kernel (gram).	Proteid nitrogen (gram) in—	
					Kernels.	Average kernel.
32608	July 27	1.0183	3.78	0.01851	0.03849	0.0006998
33305	do	3.1346	3.41	.02090	.10689	.0007126
33407	do	7.0889	1.62	.02271	.11223	.0003679
33408	do	1.1132	1.39	.01446	.01547	.0002009
33605	do	7.0596	2.39	.02345	.16872	.0005605
33606	do	8.1890	2.21	.02144	.18098	.0004738
33607	do	2.8903	3.22	.02125	.09307	.0006843
34405	do	4.1281	4.33	.01994	.17875	.0008635
34606	do	6.1962	3.12	.02213	.19332	.0006904
36905	do	5.0200	3.88	.01880	.19478	.0007295
37305	do	6.1394	2.96	.01987	.18173	.0005881
37705	do	8.0905	2.64	.01972	.23998	.0005327
37706	do	1.2069	2.34	.02155	.02824	.0005053
37707	do	3.3004	2.93	.01710	.09670	.0005010
37905	Aug. 4	.9452	2.53	.02555	.02391	.0006433
38005	July 27	2.5134	2.84	.01808	.07138	.0005135
38505	do	12.1088	3.61	.02252	.43713	.0007764
39205	do	21.5399	2.11	.02089	.45435	.0004407
39405	do	9.3541	2.88	.02093	.21399	.0006027
39506	Aug. 4	1.9218	2.93	.02869	.05631	.0008404
39507	July 27	1.8862	3.02	.01699	.05696	.0005132
39606	do	4.6383	2.37	.01341	.10967	.0003177
40505	do	4.1546	2.82	.02444	.11716	.0006892
42205	do	1.8494	3.63	.01967	.06713	.0007142
42405	do	1.4892	3.07	.02251	.04572	.0006927
43405	do	2.8000	2.92	.02258	.08176	.0006594
43505	Aug. 4	1.4464	4.13	.01555	.05974	.0006423
44605	July 27	1.1271	2.86	.02049	.03223	.0005861
46105	do	4.6146	3.00	.01775	.13843	.0005324
46106	do	1.6103	2.54	.01964	.04090	.0004988
48705	do	4.3615	3.13	.01652	.13652	.0005171
49505	do	1.2716	3.24	.01898	.04120	.0006149
49905	do	.6760	3.62	.02939	.02436	.0010640
50906	do	1.7280	3.57	.01516	.06169	.0005411
55508	do	3.7407	3.11	.01732	.11636	.0005386
58806	do	1.9469	1.88	.02049	.03660	.0003853
58905	do	2.3031	2.43	.01355	.05596	.0003292
59605	do	7.1828	2.12	.01880	.15228	.0003986
63506	do	2.3986	2.44	.01568	.05853	.0003825
66005	do	7.6690	2.63	.02073	.20170	.0005451
69506	do	13.5696	2.50	.02047	.33923	.0005117
69805	do	2.4420	5.82	.02220	.14213	.0012921
69806	do	12.0136	1.66	.02153	.19943	.0003574
72405	do	8.4415	3.36	.03963	.28363	.0013316
72406	do	8.2929	2.95	.01929	.24464	.0005689
72905	do	2.6462	2.48	.01585	.06563	.0003930
73307	do	.5572	2.39	.02229	.01332	.0005327
73308	do	14.2986	2.92	.02291	.41752	.0006539
74305	do	4.4222	1.98	.02047	.08756	.0004054
74506	do	.4096	2.73	.01781	.01118	.0004862
74508	do	.8172	2.60	.01434	.02125	.0003728
76205	do	8.4407	2.35	.01695	.19836	.0003982
80505	do	15.7835	1.81	.02165	.28569	.0003919
81405	do	4.5737	2.62	.01862	.11710	.0004879
81406	do	1.2391	3.31	.01721	.04101	.0005697
84405	do	8.7448	2.48	.02043	.21687	.0005067
85205	do	3.4766	2.60	.01625	.09039	.0004224
86105	do	3.0282	2.56	.01495	.07964	.0003923
86106	do	7.6241	2.63	.01749	.20052	.0004599
Average	July 27.2	4.6626	2.94	.01992	.12854	.0005800

TABLE 32.—*Summary of yield and nitrogen content of grain, tabulated according to length of growing period.*

Plants grouped according to date ripe.	Number of analyses.	Average date ripe.	Yield (grams).	Percentage of proteid nitrogen.	Weight of average kernel (gram).	Proteid nitrogen (gram) in—	
						Kernels.	Average kernel.
July 7 to 11	49	July 8.9	9.9067	2.69	0.02024	0.26175	0.0005356
July 11 to 15	65	July 13.	7.6611	2.81	.01887	.20820	.0005290
July 15 to 19	50	July 16.2	5.1354	2.87	.01869	.14452	.0005222
July 19 to 23	56	July 20.1	6.5399	2.93	.01886	.18064	.0005482
July 23 to 27	52	July 23.2	4.9015	2.93	.01878	.13654	.0005544
July 27, or later	83	July 27.2	4.6636	2.94	.01992	.12854	.0005800

TABLE 33.—*Summary of nitrogen content, etc., tabulated according to yield per plant.*

Plants grouped according to yield (in grams).	Number of analyses.	Average date ripe.	Yield (grams).	Percentage of proteid nitrogen.	Weight of average kernel (gram).	Proteid nitrogen (gram) in—	
						Kernels.	Average kernel.
Below 1	31	July 20.2	0.6049	2.91	0.01683	0.01731	0.0004916
1 to 2.5	67	July 21.9	1.7673	3.09	.01852	.05456	.0005730
2.5 to 5	88	July 20.	3.5683	3.03	.01796	.10794	.0005445
5 to 10	94	July 18.3	7.6706	2.68	.01997	.20270	.0005351
10 to 15	52	July 15.1	12.2573	2.71	.02168	.33433	.0005774
15 to 20	20	July 15.1	17.1908	2.54	.02103	.43921	.0005382
More than 20	4	July 14.5	23.7186	2.55	.02159	.60401	.0005450

TABLE 34.—*Summary of yield, etc., tabulated according to nitrogen content.*

Plants grouped according to percentage of nitrogen.	Number of analyses.	Average date ripe.	Yield (grams).	Percentage of proteid nitrogen.	Weight of average kernel (gram).	Proteid nitrogen (gram) in –	
						Kernels.	Average kernel.
Below 1.5	4	July 22.5	5.8099	1.35	0.01709	0.07290	0.0002266
1.5 to 2	25	July 18.5	2.7423	1.80	.02124	.11620	.0003867
2 to 2.25	18	July 19.8	8.9542	2.12	.02030	.19070	.0004325
2.25 to 2.5	47	July 17.3	7.3389	2.39	.02000	.18478	.0004773
2.5 to 2.75	82	July 16.3	8.0817	2.63	.01938	.21280	.0005102
2.75 to 3	67	July 19.6	5.9093	2.85	.01910	.16609	.0005454
3 to 3.25	47	July 21.2	4.4497	3.11	.01824	.13847	.0005667
3.25 to 3.5	20	July 20.7	4.6756	3.37	.01870	.15189	.0006213
3.5 to 4	23	July 21.5	3.6486	3.68	.01852	.13513	.0006807
More than 4	25	July 19.5	4.5431	4.72	.01819	.21239	.0008639

RELATION OF SIZE OF HEAD TO YIELD, HEIGHT, AND TILLERING OF PLANT.

The size of the head has always been considered to be closely connected with the productiveness of wheat. The well-known work of Hallet in increasing the yielding qualities of wheat is perhaps the best example of wheat improvement by the selection of plants having large heads. Whether large heads or a large number of medium-sized heads on a plant are more desirable is still a question.

Table 35 gives the yields, etc., of between 300 and 400 plants, tabulated according to the number of kernels on the head. Table 36 is a summary of these, while Tables 37 and 38 consist of the same data tabulated according to the yield per plant and yield per head, respectively.

It will be seen from Table 36 that the heads of slightly more than medium size produced the largest yields of grain; that the weight of the average kernel did not increase with the size of the head, nor did it decrease except on the very largest heads; that the plants with somewhat more than average-sized heads were the tallest, and that the plants with medium-sized heads or slightly less tillered most largely.

Table 37 shows that with an increased yield per plant there is a constant increase in the height and tillering of the plant.

Table 38 indicates that the yield per head and yield per plant do not increase together, but that the largest yielding plants are those of medium yield per head. The same would seem to be true of the height and tillering of the plant. The weight of the average kernel increases quite uniformly with the yield per head.

In considering these results it must be borne in mind that these plants were grown 6 inches apart each way, and were therefore not under the conditions that would obtain in a thickly drilled or broadcasted field, where lack of ability to tiller would be compensated for by the larger number of plants. However, the variety of wheat yielding best in Nebraska is one having only a medium-sized or even small head, as compared with most wheats, but it is a strong-tillering variety.

TABLE 35.—*Relation of size of head to yield, height, and tillering of plant.*

SIZE OF HEAD, BELOW 16 KERNELS.

Record number.	Size of head.	Yield per plant (grams).	Yield per head (grams).	Weight of average kernel (grams).	Height (cm.).	Tillering.
17308	15.2	1.2275	0.3069	0.02012	59	5
17406	15.5	2.0907	.2613	.01686	65	11
18805	15.2	2.1462	.2385	.01567	65	18
20708	13.6	2.4690	.2743	.02024	60	11
21211	10.0	.2806	.2806	.02806	45	2
22209	15.5	.4336	.2168	.01399	70	6
26805	15.7	4.9456	.3533	.02248	68	26
32207	13.8	1.2573	.2515	.01822	47	5
37905	12.3	.9452	.3151	.02555	52	3
39506	11.2	1.9218	.3203	.02869	48	6
42206	12.5	.3161	.1580	.01264	63	5
44607	12.6	2.5235	.2281	.02035	52	12
48408	13.5	.3485	.1742	.01291	45	3
49905	11.5	.6760	.3380	.02939	49	2
50705	15.0	.5958	.2979	.01986	40	3
73307	12.5	.5572	.2786	.02229	46	4
74506	12.5	.4096	.2048	.01781	68	2
94105	11.0	.5595	.2797	.02543	51	1
Average	13.3	1.3169	.2654	.02059	55.2	6.9

SIZE OF HEAD, 16 TO 20 KERNELS.

17410	19.1	16.9987	0.4358	0.02285	84	46
21205	17.6	2.3642	.3378	.01922	55	10
21305	16.4	6.2514	.3290	.02004	65	21
21307	17.9	2.5691	.3211	.01796	53	10
21705	19.3	1.5420	.5140	.02659	73	3
21710	19.7	.8478	.2826	.01437	59	5

TABLE 35.—*Relation of size of head to yield, height, and tillering of plant*—Continued.

SIZE OF HEAD, 16 TO 20 KERNELS—Continued.

Record number.	Size of head.	Yield per plant (grams).	Yield per head (grams).	Weight of average kernel (grams).	Height (cm.).	Tillering.
21807	18.8	9.4172	0.4709	0.02498	77	25
22207	18.8	3.2787	.3643	.01940	65	16
22208	16.8	1.9090	.2727	.01619	57	8
26906	19.0	4.2376	.3531	.01859	70	16
26909	18.0	2.9999	.3000	.01667	50	10
28206	19.9	4.3698	.3972	.01996	80	26
33106	18.0	.3089	.3089	.01716	43	2
37706	18.7	1.2069	.4023	.02155	42	4
37906	19.0	.2063	.2063	.01086	50	2
38005	19.8	2.5134	.3591	.01808	53	7
38607	19.0	.3037	.3037	.01598	56	2
38608	17.6	3.0228	.3359	.01913	60	11
38609	19.5	6.7665	.4511	.02309	65	6
42205	18.8	1.8494	.1699	.01967	68	6
44605	18.3	1.1271	.3757	.02049	53	3
44606	17.7	2.5235	.3605	.02035	52	8
48405	19.0	.9701	.2425	.01276	55	5
50706	17.5	.4701	.2350	.01343	38	2
55905	18.4	5.7948	.3219	.01751	75	34
55906	19.2	7.9968	.3076	.01603	85	40
56105	17.7	5.7431	.3023	.01709	70	35
56207	17.7	10.9073	.4195	.02361	84	42
57307	16.3	4.7117	.2945	.01801	67	17
69705	17.4	3.7810	.2701	.01550	88	28
74508	19.0	.8172	.2724	.01434	50	4
81708	19.1	7.3993	.4933	.02578	86	20
88608	18.5	1.5355	.3839	.02075	69	4
92207	19.0	3.6926	.3357	.01767	73	15
92505	17.3	2.6615	.2957	.01706	68	12
95510	19.9	2.8356	.3544	.01783	70	8
Average	18.4	3.7758	.3383	.01862	64.1	13.7

SIZE OF HEAD, 20 TO 24 KERNELS.

17305	22.9	3.6302	0.4538	0.01984	61	12
17408	23.7	9.2038	.4383	.01852	73	24
17507	21.5	.7720	.3860	.01795	78	4
20705	21.8	1.8517	.3703	.01698	55	6
20706	23.3	3.3138	.4734	.02033	61	7
20707	21.1	9.9070	.4718	.02282	75	22
20709	23.5	5.3229	.4839	.02063	67	13
21207	23.6	2.3066	.4613	.01955	60	6
21212	21.0	1.7216	.4304	.02049	50	5
21306	22.6	4.1516	.4152	.01837	60	11
21707	23.3	12.3685	.4947	.02125	90	24
21708	20.5	9.2850	.4887	.02381	85	26
21809	20.9	8.0214	.4011	.01919	84	25
21811	21.0	11.9114	.4412	.02101	87	29
21812	22.9	14.8139	.3445	.01507	90	54
21907	22.6	2.9248	.4178	.01851	82	8
22205	23.6	2.6965	.2247	.00953	80	54
26106	22.5	2.0737	.5184	.02304	60	9
26806	21.7	2.7255	.3894	.01793	56	12
26807	21.8	17.2324	.5222	.02390	76	40
27207	20.7	3.3266	.4158	.02004	75	9
27307	23.8	3.0850	.4407	.01847	80	10
27505	21.6	12.0399	.4815	.02183	84	38
28805	21.7	2.1851	.5463	.02512	65	6
33105	22.0	2.5601	.4267	.01939	65	12
33405	23.4	8.1268	.4515	.01930	68	20
33407	21.8	7.0889	.5063	.02271	67	18
33906	23.8	2.2862	.4572	.01921	67	9
38606	22.3	8.4605	.4700	.02110	71	21
38706	21.5	7.2545	.4267	.01988	75	30
40405	23.0	.6316	.3158	.01373	54	3
43505	23.2	1.4464	.3616	.01555	45	3
45605	20.3	.7081	.2360	.01161	55	6
45705	22.0	.7532	.3766	.01712	58	6
48106	21.0	11.6655	.4023	.01919	79	39
48305	23.6	12.0278	.6014	.02543	81	28
48406	22.6	3.2964	.2997	.01321	68	13
48507	23.3	1.6036	.5345	.02296	63	7

TABLE 35.—*Relation of size of head to yield, height, and tillering of plant*—Continued.

SIZE OF HEAD, 20 TO 24 KERNELS—Continued.

Record number.	Size of head.	Yield per plant (grams).	Yield per head (grams).	Weight of average kernel (grams).	Height (cm.).	Tillering.
48806	21.0	9.8346	0.3782	0.01798	78	12
55205	20.0	.6893	.3446	.01723	56	6
55606	22.9	11.0930	.5042	.02205	92	24
55907	21.4	19.3966	.5542	.02590	95	42
55908	23.4	12.2210	.5092	.02175	95	40
55909	21.5	9.2120	.6580	.03050	85	31
56205	23.8	6.5232	.4659	.01959	82	29
56206	20.4	9.3093	.3724	.01829	86	42
56208	22.5	13.5720	.5429	.02356	88	51
56209	21.1	15.8086	.3513	.01664	90	67
57005	22.0	1.5364	.3841	.01746	73	7
57105	23.9	3.7263	.2192	.00916	85	40
57305	22.8	8.5777	.3899	.01666	78	30
57306	21.7	7.9772	.3989	.01838	80	23
57308	21.4	9.8378	.3644	.01705	80	40
57505	22.5	2.7616	.3452	.01534	72	18
57507	23.9	6.9861	.4657	.01946	78	26
57508	22.3	12.0728	.7102	.03177	85	22
63105	22.5	1.5452	.3883	.01717	68	8
63106	23.6	3.3006	.4715	.02001	77	9
63107	21.9	9.3120	.4901	.02233	80	25
72605	21.7	1.1166	.3722	.01718	52	3
72705	21.9	9.1522	.5384	.02191	68	20
74305	21.6	4.4222	.4422	.02047	60	11
74507	20.5	9.2130	.3839	.01869	70	27
74605	21.0	7.1181	.3746	.01784	69	27
74606	23.2	9.6451	.4822	.02079	75	24
76205	21.7	8.4407	.3670	.01695	70	26
81405	21.8	4.5737	.4158	.01862	70	11
81705	21.1	9.7922	.4451	.02106	82	27
81706	21.2	15.3928	.4527	.02132	90	40
81707	23.8	18.3614	.5564	.02336	96	53
81709	20.5	16.4092	.4451	.02175	90	45
84405	23.8	8.7448	.4858	.02043	75	19
88607	23.4	5.1584	.5158	.02205	73	15
91905	22.0	3.4436	.3826	.01739	72	12
91906	22.2	3.5486	.3943	.01774	74	11
92206	23.0	1.1074	.5537	.02407	66	3
92305	22.9	2.3859	.3408	.01491	65	11
92306	23.1	6.0091	.4006	.01732	75	19
92506	22.9	3.8709	.3871	.01690	77	16
92507	22.0	9.6779	.4208	.01916	82	29
Average.	22.2	6.8466	.4355	.01953	73.8	21.4

SIZE OF HEAD, 24 TO 28 KERNELS.

1730[illegible]	24.3	3.9968	0.3997	0.01645	66	12
17405	25.1	15.0996	.5414	.02127	72	34
17409	24.3	14.8957	.4514	.01857	85	39
20710	25.5	17.1115	.5032	.01974	77	39
21206	24.8	2.8564	.4761	.01917	62	6
21308	25.3	5.8080	.4149	.01641	54	14
21706	26.9	19.3318	.6444	.02390	88	38
21709	25.8	7.7296	.5521	.02141	85	23
21711	24.2	17.1820	.4773	.01968	85	51
21806	24.9	14.2450	.5935	.02378	91	32
21808	25.7	19.7446	.4388	.01708	96	57
21810	26.0	1.0304	.5152	.01982	55	4
21913	27.3	10.1925	.5662	.02072	84	27
22210	27.1	6.0173	.5470	.02019	78	31
26808	24.7	3.8811	.4312	.01748	64	11
26905	25.1	6.4102	.4931	.01966	66	15
26908	24.0	3.9797	.4974	.02073	62	9
27205	26.2	16.4061	.4825	.01841	87	57
27305	24.3	5.5666	.5061	.02085	80	22
27506	24.7	10.0005	.5556	.02252	85	23
27507	25.0	1.3746	.4582	.01833	50	4
27508	27.9	5.5324	.6137	.02287	78	19
32008	27.5	1.0183	.5091	.01851	50	2
33107	24.5	6.1026	.4694	.01919	73	29
33305	25.0	3.1346	.5224	.02090	53	7
33406	25.7	4.6045	.4186	.01627	72	16
33408	25.7	1.1132	.3711	.01446	56	4

TABLE 35.—*Relation of size of head to yield, height, and tillering of plant*—Continued.

SIZE OF HEAD, 24 TO 28 KERNELS—Continued.

Record number.	Size of head.	Yield per plant (grams).	Yield per head (grams).	Weight of average kernel (grams).	Height (cm.).	Tillering.
33605	27.4	7.0596	0.6418	0.02345	65	14
33606	27.3	8.1890	.5489	.02144	72	17
33607	27.2	2.8903	.5781	.02125	58	6
33905	26.7	11.1476	.5867	.02194	77	23
34207	26.6	13.5556	.5894	.02219	77	22
37705	25.6	8.0905	.4495	.01972	60	22
39507	27.8	1.8862	.4715	.01699	59	4
45606	24.4	4.0358	.4484	.01834	59	13
48306	26.2	2.6571	.4428	.01692	58	7
48407	26.6	11.2890	.4181	.01572	82	53
48409	26.2	6.4302	.5358	.02048	74	19
48505	27.4	1.9154	.3831	.01398	70	7
48508	27.4	11.2008	.5091	.01858	80	36
55506	27.1	17.8506	.5578	.02062	95	58
56107	24.9	14.4556	.3023	.01658	90	49
57509	27.8	10.6261	.4830	.01739	84	37
57606	26.4	3.0790	.6158	.02333	78	8
57607	27.3	16.4433	.6090	.02234	87	48
57608	24.3	8.6189	.4788	.01968	83	38
58206	24.7	1.3961	.2327	.00943	75	29
63506	25.5	2.3986	.3998	.01568	64	7
65305	26.0	1.8018	.6006	.02310	65	10
65306	25.9	9.8298	.4681	.01807	75	28
65308	26.5	11.7066	.5321	.02008	77	35
66008	24.9	3.1555	.4505	.01814	76	8
69505	25.5	4.7116	.4712	.01847	66	13
69805	27.5	2.4420	.6105	.02220	62	7
69806	27.9	12.0136	.6007	.02153	75	28
72606	27.1	9.3629	.4681	.01724	82	26
72607	26.9	3.4442	.4920	.01832	74	8
72905	27.8	2.6462	.4410	.01585	59	5
74607	25.8	8.3406	.4390	.01699	76	31
80305	25.1	15.7835	.5442	.02165	70	33
81406	24.0	1.2391	.4130	.01721	55	3
81710	24.7	9.1411	.5713	.02308	90	24
84906	25.5	7.5438	.5029	.01975	65	16
85205	26.7	3.4766	.4386	.01625	65	11
86105	25.4	3.0282	.3785	.01495	68	4
86106	27.2	7.6241	.4765	.01749	76	25
88606	25.3	9.9456	.5234	.02068	85	23
88609	24.7	9.8719	.5196	.02100	74	26
88905	26.6	5.3069	.4824	.01811	82	17
92205	26.5	5.2616	.4047	.01525	72	18
92405	26.7	3.4356	.4294	.01605	78	10
92407	26.5	.8983	.4491	.01695	68	2
92907	24.3	4.4673	.4964	.02040	84	10
94206	25.1	7.5006	.4688	.01866	76	19
94208	24.8	3.7828	.2909	.01175	71	19
94407	26.2	6.7664	.4229	.01615	82	23
94907	27.2	12.1918	.5301	.01948	85	23
94908	25.0	2.3678	.4736	.01894	73	9
94909	24.2	3.6977	.2631	.01696	72	9
95506	25.9	11.0548	.4806	.01852	86	25
95507	26.0	12.1592	.5527	.02029	90	22
95508	25.5	14.4617	.4987	.01954	97	31
95705	26.5	10.3426	.4309	.01626	80	31
95707	26.0	.7577	.3788	.01457	67	4
Average.	25.9	7.5207	.4848	.01874	73.8	21.2

SIZE OF HEAD, 28 TO 32 KERNELS.

17505	29.0	0.3885	0.3885	0.01340	46	7
17506	31.0	2.2881	.7627	.02460	55	6
20805	31.7	14.6942	.6679	.02157	85	30
21208	28.7	5.1594	.5159	.01798	63	11
21209	29.7	1.4484	.4828	.01627	51	6
21210	29.6	3.9143	.4893	.01577	59	8
21805	29.3	20.9290	.4983	.01699	91	48
21905	28.2	14.3111	.5111	.01809	92	62
21906	31.4	10.4800	.8062	.02563	88	27
21908	28.8	3.5574	.5929	.02056	92	9
21909	30.9	12.1819	.7166	.02317	86	29
21911	29.5	8.4593	.6597	.02209	90	23

TABLE 35.—*Relation of size of head to yield, height, and tillering of plant*—Continued.

SIZE OF HEAD, 28 TO 32 KERNELS—Continued.

Record number.	Size of head.	Yield per plant (grams).	Yield per head (grams).	Weight of average kernel (grams).	Height (cm.).	Tillering.
22206	29.2	2.5712	0.5142	0.01720	70	9
22211	28.0	11.5675	.5784	.02062	88	59
26107	28.8	2.0390	.4078	.01416	67	6
27005	28.9	16.4120	.5471	.01895	77	40
27206	28.8	19.1854	.7106	.02469	90	49
27306	28.5	13.3011	.5542	.01945	88	48
27308	31.7	4.5123	.5640	.01777	88	11
27509	30.4	5.3615	.6702	.02206	73	9
32206	28.2	10.4036	.5779	.02052	71	26
32605	28.1	5.2268	.6533	.02323	71	9
32606	31.3	2.0162	.6721	.02145	69	3
34205	30.9	9.1498	.6100	.01972	78	19
34208	31.2	2.9886	.5977	.01916	66	5
37305	30.9	6.1394	.6139	.01987	58	12
38505	29.6	12.1088	.6373	.02252	70	21
38506	28.3	1.6799	.5600	.01975	54	3
38605	30.5	1.2124	.6062	.01987	55	2
39405	31.9	9.3541	.6681	.02093	74	18
39606	31.4	4.6383	.4217	.01341	64	18
40305	29.8	3.6003	.6000	.02011	62	6
44505	30.9	5.9990	.5453	.01764	69	25
45005	29.4	3.2340	.4042	.01376	66	9
45805	31.0	1.5298	.3824	.01234	48	4
46107	31.9	8.3935	.5595	.01756	79	27
50905	31.6	2.3982	.3426	.01085	68	10
50906	28.5	1.7280	.4320	.01516	58	5
55005	30.2	7.9684	.6129	.02028	75	19
55006	30.1	7.1852	.4790	.01593	80	19
55007	29.5	2.1571	.5393	.01828	65	7
55206	30.4	11.3592	.5978	.01965	82	27
55306	30.6	4.1323	.5903	.01931	77	17
55307	31.1	5.6864	.5169	.01663	80	19
55507	31.5	9.8228	.6139	.01949	95	28
56106	28.0	12.0161	.5224	.01866	90	33
57006	30.5	10.1836	.4427	.01453	88	41
57407	31.8	14.9992	.6250	.01968	92	41
58207	30.7	4.2207	.4221	.01375	75	18
58505	31.1	7.4516	.6210	.02730	80	18
58806	31.7	1.9469	.6489	.02049	65	7
59606	29.8	9.7084	.5109	.01712	80	37
63505	29.7	4.0230	.5747	.01934	66	8
65307	31.1	7.0051	.5838	.01878	74	17
66005	30.8	7.6690	.6391	.02073	75	22
69506	30.1	13.5696	.6168	.02047	73	24
71905	29.3	28.2136	.6561	.02239	80	46
72406	30.7	8.2929	.5923	.01929	70	15
72706	29.5	14.6802	.7340	.02484	80	27
72707	28.1	4.5806	.5726	.02036	72	8
76206	29.8	5.4411	.3627	.01217	73	30
88906	30.3	9.9034	.5502	.01814	80	21
92408	29.6	3.7820	.5403	.01827	81	7
92908	31.2	3.2388	.5398	.01732	76	7
94205	31.3	1.2117	.4039	.01893	55	6
94207	29.9	13.7057	.5711	.01909	83	31
94209	31.7	3.6006	.6001	.01895	75	7
94406	28.9	10.5556	.5556	.01923	82	22
94605	28.0	.7319	.3659	.01307	68	7
94606	29.9	11.8435	.5383	.07544	84	23
94905	31.8	4.4423	.4936	.01553	75	11
94906	29.8	12.3862	.5385	.01808	91	24
95706	29.7	5.1629	.5736	.01934	82	9
Average.	30.1	7.4992	.5598	.01958	74.5	19.4

TABLE 35.—*Relation of size of head to yield, height, and tillering of plant*—Continued.

SIZE OF HEAD, 32 TO 36 KERNELS.

Record number.	Size of head.	Yield per plant (grams).	Yield per head (grams).	Weight of average kernel (grams).	Height (cm.).	Tillering.
17307	34.5	3.1454	0.7863	0.02279	70	8
18905	34.3	1.4864	.4955	.01443	50	4
26105	32.7	1.8242	.4560	.01393	69	13
26907	34.0	1.8276	.6092	.01792	55	8
28806	34.2	14.4630	.7232	.02111	75	30
34405	34.5	4.1281	.6881	.01994	62	8
34606	35.0	6.1962	.7745	.02213	61	13
36905	33.4	5.0200	.6275	.01880	58	7
39205	32.2	21.5399	.6731	.02089	82	40
42405	33.0	1.4892	.7446	.02251	60	2
42905	33.5	1.2499	.6249	.01866	68	4
48506	32.7	9.4585	.5564	.01701	82	30
49505	33.5	1.2716	.6358	.01898	60	3
51005	34.5	15.5835	.6233	.01804	75	32
55008	33.7	17.4226	.6222	.01846	82	30
55305	33.4	2.5160	.5032	.01507	75	12
55308	33.1	9.5078	.7923	.02395	79	28
55605	33.3	10.9180	.7279	.02184	89	23
55607	34.5	2.3931	.5983	.01734	77	7
55608	33.5	22.5848	.9034	.02699	95	31
57007	33.6	3.3176	.6635	.01975	90	9
57406	33.7	2.4923	.6231	.01846	92	14
57408	35.0	12.2004	.7177	.02047	90	26
58805	35.1	23.1471	.7014	.01999	78	51
60305	35.0	.5952	.5952	.01701	57	4
69305	34.3	2.0430	.6810	.01984	70	7
72405	35.5	8.4415	1.4069	.03963	67	6
72708	33.2	9.0386	.7532	.02270	78	12
73308	34.7	14.2986	.7944	.02291	74	23
85206	34.2	4.9315	.4483	.01312	69	13
88605	34.5	1.6362	.8181	.02731	70	3
91305	34.5	3.0940	.7735	.02242	76	6
92208	35.3	6.6206	.6621	.01876	78	17
92406	34.5	8.2366	.7488	.02168	81	17
92409	35.0	5.7131	.6348	.01814	81	13
92905	35.2	2.7000	.5400	.01534	75	6
92909	33.1	10.1363	.6335	.01916	86	21
95509	34.5	2.9475	.7369	.02136	74	4
Average.	34.1	7.2530	.6868	.02023	73.9	15.4

SIZE OF HEAD, 36 KERNELS AND OVER.

18906	65.0	0.9229	0.9229	0.01420	67	5
21813	43.2	4.0258	.8051	.01877	80	21
34206	40.5	1.5940	.7970	.01968	74	5
37707	38.6	3.3004	.6601	.01710	64	5
40205	38.8	3.6302	.7260	.01871	65	11
40505	42.5	4.1546	1.0386	.02444	60	4
43405	41.3	2.8000	.9333	.02258	64	3
46105	37.1	4.6146	.6592	.01775	73	8
48705	44.0	4.3615	.7269	.01652	80	7
48706	47.4	6.1986	.7748	.01635	78	12
55508	36.0	3.7407	.6222	.01732	73	12
57405	41.0	.8328	.8328	.02031	73	1
57805	38.6	4.8988	.6998	.01814	76	17
57905	36.8	2.4731	.4122	.01118	74	17
58705	58.7	2.5436	.6359	.01082	68	11
58905	42.5	2.3031	.5758	.01355	66	13
59605	38.2	7.1828	.7183	.01880	77	30
62805	37.0	1.3451	.4484	.01212	70	11
66006	52.3	6.0090	.8584	.01642	73	12
72806	36.7	2.0970	.6990	.01906	62	5
73306	37.6	8.5373	.7761	.02062	78	20
81505	48.7	2.8327	.9442	.01940	78	7
84905	37.0	.7130	.7130	.01927	47	4
92906	36.2	2.8816	.5763	.01592	75	7
95505	37.0	.3146	.3146	.00850	79	3
Average.	42.1	3.3723	.7148	.01710	71.0	10.2

TABLE 36.—*Summary of relation of size of head to yield, height, and tillering of plant.*

Classification according to number of kernels on head.	Number of plants.	Average number of kernels on spike.	Yield per plant (grams).	Yield per head (gram).	Weight of average kernel (gram)	Height (cm.).	Tillering.
Below 16	18	13.3	1.3169	0.2654	0.02059	55.2	6.9
16 to 20	36	18.4	3.7758	.3383	.01862	64.1	13.7
20 to 24	80	22.2	6.8466	.4355	.01953	73.8	21.4
24 to 28	84	25.9	7.5207	.4848	.01874	73.8	21.2
28 to 32	73	30.1	7.4992	.5598	.01958	74.5	19.4
32 to 36	38	34.1	7.2530	.6868	.02023	73.9	15.4
More than 36	25	42.1	3.3723	.7148	.01710	71.0	10.2

TABLE 37.—*Relation of yield of plant to height and tillering, and to the yield per head.*

Classification according to yield per plant, in grams.	Number of plants.	Yield per plant (grams).	Height (cm.).	Tillering.	Yield per head (gram).
Below 1	31	0.6050	56.5	3.7	0.3553
1 to 2.5	67	1.7673	62.2	7.0	.4740
2.5 to 5	87	3.5526	69.1	11.6	.4917
5 to 10	93	7.6485	75.4	22.1	.5320
10 to 15	51	12.2862	84.4	32.3	.5592
15 to 20	20	17.1908	84.6	42.9	.5310
More than 20	5	23.2829	85.2	43.2	.6865

TABLE 38.—*Relation of yield per head to yield, height, and tillering of plant, and to weight of average kernel.*

Classification according to yield per head, in grams.	Number of plants.	Yield per head (gram).	Yield per plant (grams).	Height (cm.).	Tillering.	Weight of average kernel (gram).
Below 0.300	30	0.2484	1.6939	60.8	11.4	0.01586
0.300 to 0.400	62	.3567	3.7365	65.6	15.5	.01737
0.400 to 0.500	98	.4524	6.7326	72.8	19.9	.01847
0.500 to 0.600	78	.5477	9.5646	76.6	21.8	.02073
0.600 to 0.700	50	.6372	7.6214	74.3	17.3	.02056
0.700 to 0.800	25	.7456	4.4523	75.2	18.6	.02179
More than 0.800	12	.9229	5.7687	73.7	10.3	.02151

SUMMARY AND CONCLUSIONS.

As between wheat kernels of the same variety raised under similar conditions, those kernels having a high percentage of proteid material have a lower specific gravity, weigh slightly less, and occupy a smaller volume than kernels having a smaller percentage of proteids.

As between individual spikes and individual plants, the same relations obtain.

As between individual plants in different years, these relations do not hold.

The quality of high proteid content and its correlated properties may be due to immaturity in the kernel, or they may belong to the normal and fully ripened kernel.

As between kernels, spikes, and plants, those kernels of greater weight contain a larger weight of proteids—this in spite of the fact that they contain a lower percentage.

Plants bearing the largest number of kernels have kernels of more than medium but not the greatest weight, as do also plants producing the greatest weight of kernels. The same is true of plants producing the greatest weight of proteid matter and gluten.

Heavy seed wheat drilled at the rate of 1½ bushels per acre produced a much larger crop of seed the first year of the separation than did light seed drilled at the same rate, but by continuing the separation of the respective crops and selecting heavy seed from the crop grown from heavy seed, and light seed from the crop grown from light seed, the difference in yield in three or four years was small.

After the first year of separation the light seed produced a greater amount of proteids per acre than did the heavy seed.

A determination of the total or of the proteid nitrogen content in the kernels on one row of spikelets of wheat affords a fairly close estimate of the same constituents in the kernels on the other row of spikelets.

A determination of the total or of the proteid nitrogen content in the kernels on one-half of the spikes on a wheat plant will give a very good estimate of the same constituents in the kernels on the other spikes, provided there are at least an average number of spikes on the plant.

There may be quite a large variation in the proteid nitrogen content of different spikes on the same wheat plant.

Determinations of the proteid nitrogen content of 800 spikes of wheat of the same variety representing different plants showed a variation of from 1.12 to 4.95 per cent of proteid nitrogen, and 351 plants of the same variety the following year varied from 1.20 to 5.85 per cent.

The proportion of gluten to proteids in kernels of different wheat plants may vary considerably. A determination of proteid nitrogen is therefore not always a guide to the gluten content of the wheat. Selection for improvement should be based on the determination of gluten.

Wheat plants having kernels high in gluten contain a smaller proportion of other proteids than do plants of medium or low gluten content.

In wheat of the same variety, raised in the same field in the same year, the ratio of gliadin to glutenin was practically the same in plants of low, medium, and high proteid nitrogen content.

It may therefore be assumed that an increase in the gluten content of a given variety of wheat raised in the same region would carry with it a corresponding improvement in its value for bread making, although there might be fluctuations from year to year in the quality of the gluten.

The content of proteid nitrogen, the kernel weight, and the total proteid nitrogen production by the wheat plant are hereditary qualities.

There is a tendency for plants possessing any of these qualities in an extreme degree to produce progeny in which the same qualities approach more closely to the average, but certain exceptional plants may transmit the same or more extreme qualities.

The yield of grain per plant after a severe winter was decreased in proportion to the susceptibility of the plant to cold. The effect of the cold caused the plant to produce a less number of heads, or, in other words, to tiller less.

The early-maturing plants yielded the most grain, and those ripening later produced in each case less when grouped into ripening periods of four days, extending through more than three weeks' time.

The early-maturing plants produced grain of slightly lower nitrogen content than the later maturing plants, and the number of grams of proteid nitrogen in the average kernel was likewise less in the early-maturing plants.

Plants with heads of slightly more than medium size produced the largest yields of grain, and were taller than plants with either larger or smaller heads. Plants with heads of medium size, or slightly less, tillered most extensively.

The weight of the average kernel did not increase with the size of the head, nor did it decrease, except on the very largest heads.

The largest yielding plants were the tallest and tillered most.

U. S. DEPARTMENT OF AGRICULTURE.
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 79.
B. T. GALLOWAY, *Chief of Bureau.*

THE VARIABILITY OF WHEAT VARIETIES IN RESISTANCE TO TOXIC SALTS.

BY

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VEGETABLE PATHOLOGICAL AND PHYSIOLOGICAL INVESTIGATIONS.

Issued July 27, 1905.

239340

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

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Pathologist and Physiologist, and Chief of Bureau.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., May 1, 1905.

Sir: I have the honor to transmit herewith a technical paper entitled "The Variability of Wheat Varieties in Resistance to Toxic Salts," and to recommend that it be published as Bulletin No. 79 of the series of this Bureau.

This paper was prepared by Mr. L. L. Harter, Scientific Assistant in the Laboratory of Plant Breeding, Vegetable Pathological and Physiological Investigations, and was submitted by the Pathologist and Physiologist with a view to publication. The subject-matter of the bulletin will be of interest to experimenters who are working on the problems of securing alkali-resistant strains of agricultural crops.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The main object of the accompanying paper is to prove that different varieties of a single species behave differently in the presence of the harmful salts that are present in the so-called alkali soils of the western United States. The work has been done with varieties of wheat on account of the great importance of that crop in the region indicated and because, being grown under a great diversity of conditions as regards climate and soil, wheat varieties would be expected to differ much among themselves in their power to withstand the effect of excessive amounts of salts in the soil, just as they differ widely in their capability of withstanding drought, cold, and parasites.

The experiments were made with young seedlings, their roots being exposed for periods of twenty-four hours to the action of pure solutions of the salts used, the greatest strength of solution in which the root tips could survive being taken as representing the limit of endurance of each variety to each salt. The salts used were the carbonate, bicarbonate, sulphate, and chlorid of sodium, and the sulphate and chlorid of magnesium. These are salts that are generally present in the largest quantity in alkali soils. Nine varieties of wheat, both from the Old World and the New, representing widely different climates and soils, were compared.

It was found that the varieties differed greatly in their ability to withstand the poisonous action of the salts used. This was more strikingly brought out in the case of some salts than of others. To magnesium sulphate, for example, some varieties are three times as resistant as are others. Tables are given in the following paper showing the limit of concentration of each of the nine varieties for each of the six salts. It was also clearly demonstrated that the different individuals of each variety differ much in resistance, and the limits of the varieties as established are only the means of the limits for all the individuals tested. Analyses of the ash of each lot of seed used were obtained from the Bureau of Chemistry, but no correlation could be shown between ash composition and resistance to action of toxic salts. On the other hand, it was clearly demonstrated that with few exceptions the varieties that have originated in arid regions, where the soils are usually more saline than in humid regions, are those that are most resistant to pure solutions of sodium and magnesium salts. Three varieties of southeastern Russia, with one exception, were found to be the most resistant of all those tested.

It is believed that the laboratory work upon which this paper is based has a direct practical bearing, as it gives us an indication of what varieties are most likely to succeed in arid regions where the soils are more or less salty. Furthermore, as some one salt—e. g., sodium chlorid—sometimes strongly predominates in the soils of a particular region, and as these experiments show clearly that, while one variety may be more resistant than another to sodium chlorid, the second is often more resistant than the first to sodium carbonate or to magnesium sulphate, we can thus obtain information as to which of the many varieties of a great crop can be sown with the best chance of success upon a given type of alkali soil. In other words, a few weeks of simple laboratory experiment may save years of costly trial in the field, although, of course, the water-culture experiments can not be considered as giving more than an indication of what we can expect each variety to do, and the final test must be the growing of the crop upon a practical scale.

The great individual variability in resistance brought out in these experiments shows that not merely have we found a guide as to which of existing varieties are best adapted to different types of saline soils, but that there is an excellent opportunity for increasing their resistance by selecting seed from the most resistant individuals. The present investigation affords further evidence that it is practicable to apply plant-breeding methods to the "alkali problem" and adapt crops by selection to the unfavorable conditions presented by soils that contain excessive amounts of soluble salts.

A. F. Woods,
Pathologist and Physiologist.

Office of Vegetable Pathological
and Physiological Investigations,
Washington, D. C., April 26, 1905.

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THE VARIABILITY OF WHEAT VARIETIES IN RESISTANCE TO TOXIC SALTS.

INTRODUCTION.

It has been shown quite conclusively in recent years that different species and genera differ very much in their ability to resist the influence of toxic salt solutions. Numerous investigations of the action of acids and salts upon plants have been made, especially during the last four or five years. Investigations of this nature are not only of great scientific interest, but promise in some cases to be of considerable practical importance. One phase of this subject which is especially interesting from this latter point of view is that of the relation of plants, particularly cultivated plants, to the components of the saline or alkaline soils that are so common in the arid part of the United States and of many other parts of the world.

A preliminary investigation of this phase of the subject was made by Messrs. Kearney and Cameron,[a] who showed by a large number of experiments on *Lupinus albus* and *Medicago sativa* that the death limit of the root tips was very different for different salts. For instance, the limit for *Lupinus albus* in sodium chlorid was found to be 0.02 of a normal solution, and in magnesium sulphate 0.00125. For *Medicago sativa*, in mixed solutions containing an excess of two calcium salts, the limit was 0.35 in magnesium sulphate and 0.20 in sodium chlorid.[b]

Much work has been done in comparing different botanical species as to their resistance to the effect of salt solutions,[c] but the compara-

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[a] Report No. 71, U. S. Dept. of Agriculture (1902).

[b] Messrs. Kahlenberg and True, who have done considerable work along this line, particularly with salts and acids, give some very interesting results. They found (On the Toxic Action of Dissolved Salts and Their Electrolytic Dissociation, Bot. Gaz., 22: 81, 1896) that *Lupinus albus* would just survive in $\frac{1}{51200}$ gram mol. per liter of copper salts. They found the same limits with ferrous sulphate ($FeSO_4$), nickel sulphate ($NiSO_4$), and cobalt sulphate ($CoSO_4$), but for mercuric chlorid ($HgCl_2$) $\frac{1}{12800}$, and mercuric cyanid ($HgCn_2$) only $\frac{1}{102400}$ gram.

[c] The experiments of Heald (On the Toxic Effect of Dilute Solutions of Acids and Salts upon Plants, Bot. Gaz., 22: 125, 1896), and later those of Moore and Kellerman, are among the most interesting in this connection.

Heald, in a series of experiments resembling those of Kahlenberg and True, obtained some valuable results with *Cucurbita pepo*, *Zea mays*, and *Pisum sati-*

tive resistance of different varieties, or races, of a single species has received little attention.[a]

During the autumn of 1903, and again in 1904, the writer had occasion to repeat, at the Department of Agriculture, Washington, D. C., the experiments previously conducted by Kearney and Cameron with

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rum. He found the limit of *Pisum sativum* to be $\frac{1}{51200}$ gram mol. per liter for copper sulphate ($CuSO_4$) as the strength which will barely permit the roots to live, and that for *Zea mays* to be $\frac{1}{25600}$. He obtained results with various salts, but this will suffice to show the variability between plants widely separated in relationship.

Moore and Kellerman (A Method of Destroying or Preventing the Growth of Algæ and Certain Pathogenic Bacteria in Water Supplies, Bul. 64, Bureau of Plant Industry, U. S. Department of Agriculture, 1904) say:

> In dealing with algæ the toxic concentration varies greatly for different genera, even for different species of the same genus. Nägeli demonstrated the extreme sensitiveness of *Spirogyra nitida* and *S. dubia* to the presence of copper coins in the water. *Oscillatoria, Cladophora, Œdogonium,* and the diatoms succumb in six hours to a copper-sulphate solution of 1 to 20,000 and in two days to 1 to 50,000 according to Bokorny. * * * According to Ono, weak solutions of the salts of most of the metals encourage the growth of algæ and fungi. Mercury and copper, however, at 0.00005 per cent and 0.00001 per cent, respectively, distinctly inhibit growth. This was the case with *Stigeoclonium, Chroococcus,* and *Protococcus.*

Moore and Kellerman have obtained results with algæ which serve very well to illustrate the variability of these organisms in the presence of the toxic copper sulphate. They found that with this salt 1 to 25,000, 1 to 75,000, and 1 to 100,000 were sufficient to kill *Raphidium polymorphum* in four days, *Desmidium swartzii* in three days, and *Navicula* sp. in five days, respectively. One part of salt to 300,000 of water and 1 to 1,000,000 were fatal to *Conferva bombycinum* in three days and *Synura uvella* in a few minutes. *Closterium moniliferum* was killed in four days in a 1 to 500,000 solution, and *Anabæna flos-aquæ* in a 1 to 5,000,000 solution in seventy-two hours. The most sensitive of all was *Uroglena americana,* practically all of which were killed in a 1 to 10,000,000 solution in sixteen hours.

[a] J. F. Breazeale informs the writer that in water-culture experiments in the laboratory of the Bureau of Soils, United States Department of Agriculture, he has found a very wide variation in the development of seedlings of different varieties of wheat when grown in the same artificial nutrient solutions and also aqueous extracts of soil, and W. H. Heileman, in the same laboratory, has shown very similar results to those presented in this investigation when using different varieties of wheat in pot cultures of natural and artificial alkali soils. It has also been shown that the vigor and rate of germination of seeds of different varieties are very different when previously soaked in any given solution of an electrolyte.

Cameron and Breazeale (The Toxic Action of Acids and Salts on Seedlings, Journal Phys. Chem., vol. 8, No. 1, p. 1, Jan., 1904) have shown a wide variation in the toxic action of different salts and acids on seedlings of plants widely separated in relationship.

From certain points of view, especially as bearing on current chemical theories, the paper of Dandeno (American Journal of Science, Vol. XVII, June, 1904) in this field is especially interesting, but a direct comparison of results in toxic salt solutions can not be made, owing to the fact that seedlings of different plants have been used.

Lupinus albus. Although the order of toxicity of the various salts remained the same in the three series of experiments, quite different limits of endurance were obtained, those in the first series made by the writer being much higher than those obtained by Kearney and Cameron and by the writer in his second series. The idea was at once suggested by these results that while possibly the second lot of seed may have differed only in being younger or otherwise more vigorous it was also possible that different varieties or even merely strains from different sources of the same species might differ considerably in their power to resist toxic salt solutions. It was therefore with a view of determining whether or not this was true that the series of experiments which forms the subject of this paper was undertaken with different varieties of wheat.

Attention should be directed at the outset to an important condition under which this work was carried on. Most of the work of this kind has been conducted with comparatively few seedlings. But individual variation in resistance is well known to be exceedingly great, and enough seedlings must be tested to eliminate all such differences. The average of the resistances of a large number of seedlings must be ascertained. The writer has in every case used from 50 to 100 seedlings, and more in some cases, the number tested being considered sufficiently large to eliminate individual variation and give fairly consistent results. The total number of seeds experimented with aggregated nearly 5,000.

The work, the results of which are shown in this paper, was taken up at the suggestion of Mr. Thomas H. Kearney, Physiologist, of the Laboratory of Plant Breeding of the Department of Agriculture.

SALTS USED.

It was decided to employ the same salts used by Kearney and Cameron in their work with *Lupinus albus*, i. e., sodium chlorid ($NaCl$), sodium sulphate (Na_2SO_4), sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), magnesium sulphate ($MgSO_4$), and magnesium chlorid ($MgCl_2$). A basis for direct comparison is thus obtained. It was thought best to use these salts, also, because of their common occurrence in saline soils, and their tendency, in a greater or less degree, to inhibit vegetable growth.

VARIETIES SELECTED.

The selection of the varieties of wheat to be used in this work has not been an easy matter, there being a number of details to consider in making the choice. To prove whether there is a difference in the power of different varieties of the same species to resist the action of toxic salt solutions it was decided to use varieties representing very different conditions of climate and soil, and selections were made, with the aid of Mr. M. A. Carleton, Cerealist of the Bureau of Plant Industry, with this end in view. All conditions under which wheat is grown are not, of course, represented. Wheat is raised in nearly every portion of the temperate zone and under as diverse conditions of soil and climate as could well be imagined. An attempt has been made, however, to obtain varieties representative of the regions presenting the greatest contrast in these respects. Cerealists have discovered that wheats well adapted to a humid region will not thrive in an arid or semiarid region, nor will varieties that are best adapted to the latter conditions thrive in a humid environment. Varieties representing each of these different climatic types were used in the experiments. Unquestionably the soils of the various regions from which the seeds were obtained differed chemically to a great extent, but in most cases data as to soil composition were not obtainable. The influence of climatic and soil factors is complicated by the fact that seeds are often transferred from one region to another. For example, a certain variety might have been grown for a number of years in strongly saline soil to which it has become thoroughly adapted, and then transferred to a semiarid region and a soil containing less salt. Were the seed procured from the new region soon after the transfer, while the variety was not yet adapted to the new conditions, probably it would still show the high degree of resistance acquired under the former conditions. In some cases it was possible to learn the exact history, for several generations, of the seed used, but in others it was impossible to obtain such definite information. To meet the conditions of the experiments it was thought advisable to select varieties from regions widely separated geographically. Therefore, one variety from Africa, two from Europe, one from Asia, and six from America were obtained. Two of the varieties are durum wheats and consequently of a different species; the rest are soft grained.

The following descriptions of the individual varieties will render more intelligible the conditions under which they grew originally:

PRESTON.

The variety of wheat known as Preston (*Triticum vulgare*) is a hybrid, produced by Dr. William Saunders, of the agricultural experiment station at Ottawa, Canada. In the spring of 1888 Doctor Saunders crossed the varieties Red Fife and Ladoga, obtaining a new sort, which was called Preston. Red Fife was taken as the male and Ladoga as the female parent. The progeny, he says, resembles somewhat both parents. The grain is very much like Red Fife. Both the parent varieties are well established in that part of Canada and were grown there with great success for many years previous to the origin of this hybrid. Preston has proved to be a better variety than either of its parents, both in yield and in range of adaptability. The region in which its parent varieties grow is very humid. Doctor Saunders claims that Preston ripens its grain from three to four days earlier than either of its parents. In view of this fact it is reasonable to conclude that it is better adapted to regions having diminished rainfall during the latter part of the season, and experience has justified the conclusion. Preston has given the best results of all the spring wheats introduced into the Northwest. It is to-day grown successfully in the southern part of Canada and in a part of the United States that includes North Dakota, eastern Montana, Minnesota, South Dakota, and Wisconsin.[a]

TURKEY.

Turkey wheat (*Triticum vulgare*) is considered the hardiest variety grown at the present time in the United States. It is a bearded sort, with white chaff, small head, and red grain. It is especially well adapted to semiarid regions, as is readily seen from the region in which it is grown. This variety was introduced into Kansas about twenty-five years ago. For a while it was confined to a small district of that State, but during the past twelve or fifteen years its excellent quality has become generally known, and consequently it is grown on a much larger area. It came originally from Crimea and other portions of Taurida, in southern Russia. That country does not differ greatly from the section of the United States in which the variety has given such good results. Though it is not a variety giving unusually heavy yields, it is well adapted to resist droughts and may be depended upon for a greater average yield than any other variety grown in Kansas. It ripens rather early, and thus escapes the excessive droughts which frequently prevail during the latter part of the wheat season in that district. It is especially adapted to the Great Plains region, including, roughly, Kansas, Oklahoma, southern Nebraska, southern Iowa, northern Texas, and portions of Missouri and Arkansas.[b]

ZIMMERMAN.

The variety known as Zimmerman (*Triticum vulgare*) is grown to some extent in the same region as the one just described. However, it has a number of essential points of difference and some characteristics that make it preferable for the experiments described here. As a whole, it is inferior to the Turkey wheat, being less resistant to drought, and it is grown principally in regions which have a greater annual rainfall. Zimmerman wheat has two good qualities to recommend it—it is beardless and ripens from four days to a week earlier than other varieties in the same locality. It is a fairly hardy sort, and is as resistant as the average variety to the cold of severe winters. It is best adapted for cultivation in southern Kansas, Oklahoma, northern Texas, Missouri, Kentucky, Tennessee, Arkansas, and farther southward. This region has a much larger annual rainfall than the one inhabited by the Turkey variety, with the exception of the States in common—Kansas, Oklahoma, and Texas.

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[a] Dr. William Saunders, Cereals and Root Crops, Ottawa, Canada, 1902.

[b] Carleton, M. A., Basis for the Improvement of American Wheats. Bul. 24, Division of Vegetable Physiology and Pathology, U. S. Department of Agriculture, 1900.

KHARKOF.

The seed used of the Kharkof variety of wheat (*Triticum vulgare*) was obtained by the United States Department of Agriculture from the Agricultural Society of Kharkof, Russia, in the Starobielsk district. Kharkof is in the southern part of Russia, about 300 miles north of the Black Sea and about 350 miles west of the Volga River. The winters are very dry and at no season of the year is the rainfall great. Kharkof is a red-bearded, hardy winter wheat. The seed was obtained from the crop grown in Russia during the season of 1902.

PADUI.

Seed of the Padui variety (*Triticum vulgare*) was obtained from Saratof, in eastern Russia. Saratof is located on the Volga River, about 400 miles from its outlet into the Caspian Sea. Padui is a soft or semihard winter wheat, and is adapted to all northern winter-wheat States from New York to Kansas and southward to the thirty-fifth parallel. The seed with which these tests have been made was imported directly from Russia. Padui is very resistant to drought, the rainfall in the region where it is grown falling as low as 12 to 15 inches per annum. This variety is cultivated to some extent in the same region as Kubanka (described later), and, therefore, is subjected to the same climate and probably to the same soil conditions.

CHUL.

Dr. E. A. Bessey describes the conditions under which the Chul variety (*Triticum vulgare*) is grown in Turkestan and in the southern part of central Asia, about Samarkand. It is found more or less in this whole steppe region, from which it derives its name, Chul meaning steppes. It is a hard grain and grows without irrigation, yields two harvests, and can be sown as either winter or spring wheat. The seed for these experiments was obtained by Doctor Bessey for the Department of Agriculture from its native country, being taken from the crop of 1902.

BUDAPEST.

The variety known as Budapest (*Triticum vulgare*) is one of the hard winter wheats imported originally from Hungary. It is now grown in Michigan and adjoining States with great success. Of all the varieties imported from Hungary, Budapest has proved the best. It is well suited for cultivation in the North Central States, including Michigan, Illinois, Indiana, Ohio, western New York, Kentucky, and perhaps farther south. It is a bearded wheat, with white chaff and red, medium hard grain. It is a success only in regions with a fairly large rainfall.

KUBANKA.

The two varieties of durum wheat (*Triticum durum*), Kubanka and Maraouani, were selected outside of the species *vulgare* in order to find types grown under extremely arid conditions. The seed of Kubanka was obtained originally from Russia. The seed used was of the fourth generation grown in the United States and should show something of the effect of soil and climatic conditions here, provided these differ essentially from those of the country where it originated. Four years is doubtless sufficient time to acclimatize the variety fairly well. Kubanka is grown in an extensive area of eastern Europe and western Asia, especially along the Volga River. The best Kubanka is found east of the Volga, on the border of the Kirghiz Steppe. It is about the only variety found along the Siberian border, where it is impossible to grow any ordinary sort because of drought, and is grown extensively by the Turgai and Kirghiz people. The rainfall over this whole region often does not exceed 10 inches per annum. The Kubanka variety matures very quickly, an absolute necessity in a region where the rainfall is very slight and often confined to a small part of the year. Because it is drought-resistant and matures early it is now being grown throughout the Volga territory from Kazan to the Caspian Sea and east to the Kirghiz Steppe and Turkestan. It is a macaroni wheat, and takes its name from Kuban territory. In this country it is best adapted for the northern plains region as far south as Kansas.

There is little doubt that the varieties Kubanka and Padui, in some regions at least, grow on soil containing considerable salt. Both varieties have become well adapted to the region just north of the Caspian Sea along the Volga River. Here salt abounds in great quantities. West of the Volga and about 100 miles from the Caspian

Sea is a great salt marsh covering a considerable area. On the other side of the river, for a couple of hundred miles along its course, there are both salt marshes and lakes. The great Khaki salt marsh along the borders of the Kirghiz Steppe covers several hundred square miles. Northward and westward from this marsh there is a series of small salt lakes, the largest of which is Elton Salt Lake. It would naturally be expected that in a region with such extensive salt marshes and lakes the arable soil would likewise contain a large proportion of salt.

MARAOUANI.

The Maraouani variety of durum winter wheat (*Triticum durum*) has been grown in northern Africa probably for centuries. As far as can be ascertained, it originated there and has long been one of the most valuable sorts of that country. The seed used in these experiments came directly from the Chéliff Valley, an arid region with very little rainfall, in the western part of Algeria. The wheat land there is cultivated for the most part without irrigation. The soil is largely a heavy clay loam, and probably contains in nearly all sections a more or less excessive amount of readily soluble salts. Maraouani is very hardy, is resistant to rusts, and has the reputation of being the best of the durum wheats now grown in that region. In the Department of Oran it is most successful when sown in November; it then matures about June. It is thought by expert cerealists that this variety would succeed well in the spring-wheat regions of the northern United States and as a winter wheat in the Southwest.

METHODS OF EXPERIMENTS.

Wheat seeds are small compared with lupines, beans, peas, etc., with which most of the work of other experimenters has been done. The rootlets of the wheat seedlings are so small that at first it was feared that some difficulty would be experienced in marking off the rapidly growing zone with india ink, the readiest method for accurate determination of the death point. In view of this difficulty the work was begun without marking. It required but a few trials, however, to prove that it would be practically impossible to obtain satisfactory results in such a way. Wheat rootlets have a hard surface and do not become flaccid in salt solutions unless these are of a concentration much beyond the toxic limit, in which case the roots become yellow and the cells somewhat broken down. However, one or two attempts at marking showed that with a little practice and care this could be effected without inflicting any injury. By rupturing the epidermis very slightly a sufficiently conspicuous mark, which will last forty-eight to seventy-two hours, can be made without injury to the roots.

The seeds were put in sphagnum moss finely broken up and kept sufficiently moist to preclude lateral branching or superfluous development of root hairs. They germinate readily in about forty-eight to seventy-two hours at an ordinary room temperature. The rootlets and leaves make their appearance almost at the same time. The number of roots varies with the variety, but is usually from three to seven. Three is the average number, five is rather common, and seven not very rare. Only one root of each seedling was marked. The initial or central one was always preferred when otherwise fit for the purpose. However, it was found after a large number of tests that the central one was most likely to become deformed while in the sphagnum moss, the tips becoming enlarged and blunt, in which case the root soon ceases to grow. When this happened side roots were preferred for marking. Rootlets which are smooth and uniform in thickness, with a rather sharp point, are most vigorous and give best results. Only experience in this work can teach one which of several roots is preferable for marking. The seeds were taken from the moss, marked, and transferred quickly to the solution. Care was taken in every way possible to avoid change of conditions during the process of making. These details will be discussed more fully in another part of this paper.

The solutions during the period of experiment were kept in the best nonsoluble beakers that could be obtained, each being large enough to hold about 300 c. c. After the solutions had been used once or twice[a] the glassware was thoroughly rinsed in distilled water before being used for the next test. Nearly every other day the beakers were thoroughly sterilized by boiling in distilled water. The beaker used is about 6½ cm. wide at the mouth, and was closed by a tight-fitting cork about 1 cm. in thickness. Each cork was perforated, and into the holes five small glass rods were inserted, bent at one end, and drawn to a sharp point. The rods were inserted with their hooked points on the inner side of the cork, and upon each a single seed was placed. The rods, as well as the corks, fit tightly and thus prevent any important amount of evaporation from the solution. They are free enough, however, to permit of the rods being raised or lowered in or out of the solution as occasion may demand. In no case were the glass rods allowed to come in contact with the solution.

Normal solutions, made with Merck's best chemically pure salts, were prepared under the supervision of Dr. F. K. Cameron, of the Bureau of Soils of the Department of Agriculture. From the normal solutions stock solutions were made up by dilution, and were kept for use as required. The solutions actually used in the experiments were made from the stock solutions by diluting with distilled water. It might seem at first that two successive dilutions would permit of an error. This, however, has been avoided in the case of chlorids and carbonates by titrating each stock solution before using. The concentration of the solutions of sulphates was frequently verified by analysis in the Bureau of Soils. Sodium carbonate and sodium bicarbonate were both titrated against N/20 hydrogen potassium sulphate, using methyl orange as an indicator. In the case of the bicarbonate solutions it was necessary to charge them with an excess of carbon dioxid to prevent their becoming alkaline. The nonalkalinity of the bicarbonate solutions was often tested by the addition of a drop of alcoholic phenolphthalein, which would indicate the presence of alkalis by forming the well-known red color. Sodium chlorid and magnesium chlorid were titrated against N/10 of silver nitrate. Whenever, upon titration, any stock solution was found to be either too dilute or too concentrated, it was corrected by the addition of more of the normal solution or by further dilution with distilled water. The water used in these experiments was distilled in the Laboratory of Plant Pathology, and near the close of the work was found by analysis in the Bureau of Chemistry to contain some slight amount of a toxic substance. That this was for all practical purposes neutralized and played no part in the toxic action of the solutions used is demonstrated in the fuller discussion of this point on page 39 of this paper.

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[a] Careful titration showed no appreciable change in the concentration of the solution after several seedlings had been kept in it for twenty-four hours, or even when the same volume was used during a second period of twenty-four hours.

All seeds for these experiments were germinated in sphagnum moss. After being finely broken up the moss was placed in a bucket and kept sufficiently moist for seed germination. It was found that the seedlings were injured if kept too moist, the roots showing an enlargement at the apex, developing into a very blunt tip, and when affected in this way they usually stopped growing and new roots were put forth. The initial radicle was more easily affected in this way. Only seedlings having healthy and vigorous rootlets were used in the experiments. The seeds were first soaked in hydrant water from four to six hours before being placed in the sphagnum moss. After about three days in the temperature of an ordinary room they were ready for use. They were most easily manipulated when the radicles were from three to four centimeters long. The root itself might well be longer, but the apical bud appears almost at the same time as the root, and when more than one or two centimeters long interferes with easy adjustment in the beakers. It was sometimes necessary to pinch off the ends of the leaves, a practice which in no way interfered with the development of the rootlets. When the radicles had reached the length mentioned above, the seedlings were taken out of the sphagnum and placed in beakers containing the solution, the tips of the roots being immersed in the liquid. One rootlet of each seedling was marked with india ink 15 mm. from the apex, which should include practically all of the rapidly growing zone. The amount of elongation during a given period could thus be determined, and this is the best means of knowing whether the root has been actually killed. Unless the concentration of the solution be far above the toxic limit the root does not become flaccid, as is the case with lupines and some other seedlings. After the roots were marked with india ink the seeds were carefully hooked on to the glass rods prepared for that purpose. As much of the root was immersed in the solution as was possible without allowing the seeds or rods to come in contact with the liquid. In all cases the entire length of the marked zone was immersed. The length of the portion of the root in the solution depended, of course, upon the total length of the root. It might at first glance seem that a variation in this respect could affect the result of the experiment, some roots having a larger surface exposed to the solution than others; but it is believed that the large number of seedlings used in each experiment practically eliminated this source of error.

All cultures were left in the solution twenty-four hours, when they were taken up and the amount of elongation of the marked portion of the root was measured and recorded. They were then transferred to a beaker containing hydrant water and allowed to remain there for another twenty-four hours, when they were taken up and the elongation again measured. The radicles which made an additional growth the second twenty-four hours in the hydrant water over the growth in the first twenty-four hours in the salt solution were considered to have survived in the solution and were thus recorded. Those making no additional growth the second twenty-four hours were considered dead and recorded in this way. Coupin and others have intimated that twenty-four hours is not sufficient to kill the plant. This objection is set aside by the consideration that only the death of the apex of the root is regarded in these experiments and not the point at which the whole plant succumbs. The object of this work is merely one of comparison of the effect of a solution of given concentration, during a definite period of time, upon different varieties. Whether this effect is expressed in the death of the whole plant or only that of a single organ is immaterial.

Control experiments were carried on every day, one in hydrant water and one in distilled water, both under conditions identical with those in the salt solutions. The results in hydrant water have been uniform from day to day and in only a few cases were they proved unsatisfactory. In such cases the whole series was discarded, the inference being that some unfavorable condition (of temperature, for example) had interfered.

A word as to the conditions of illumination and temperature during the experiments will not be out of place at this point. When in solutions the roots were exposed to the light during the day. When in the salt solutions during the first 24 hours they were kept on a shelf in the rear of a room with northern exposure only. When in hydrant water during the second 24 hours they were kept on a table at the window, under a moderately strong light. Preliminary experiments were made when commencing the work with lupines, which showed that the strength of the light, at least within the limits involved in these experiments, had no influence on the growth of the roots. Of three series of cultures, all in a solution of the same salt at the same concentration, one was placed in total darkness, another in subdued light, and a third in bright light. Otherwise they were under the same conditions. The elongation of the roots was measured at the end of 24 hours and there was no appreciable difference in the three sets of cultures.

It was impossible to keep a uniform temperature in the laboratory during the winter months, though this factor did not vary enough in either direction to cause any injury in germination or to the roots in the solution. A thermograph was kept running in the room, and a review of the records shows no temperature below 18° or above 30° C. The average temperature during the experiments was about 23° C. When making the experiments with illumination referred to above, similar ones were made to determine the influence of temperature upon the roots. The three different series of cultures (all in the same salt solution, at the same concentration) were exposed for 24 hours to temperatures of 10°, 20°, and 30° C., respectively. Results showed that the roots that had been exposed to a temperature of 20° and 30° C. showed about the same elongation, while the elongation in a temperature of 10° C. was somewhat less.

All solutions were made with water distilled from ordinary hydrant water. The receiver of the still is a porcelain tub and has been used for several years in the Laboratory of Plant Pathology of the Bureau of Plant Industry. At times the distilled water may have contained some slight traces of ammonia and doubtless some other impurities. An analysis of the water was made in the Bureau of Chemistry, and it was found to contain, in parts per million—

Zinc	Trace.
Free ammonia	0.125
Albuminoids	.014
Nitrates	None.
Nitrites	Faint traces.
Total solids (consisting of calcium, sodium, carbonates, sulphates, and chlorids)	7.4

A further discussion of the water used will be found on page 39.

METHOD OF ESTABLISHING THE TOXIC LIMITS.

Before going into details of the results obtained in the simple solutions, the methods of determining the limits of endurance of each variety to each salt will be explained. At one time the writer had thought of fixing the limit of endurance in toxic salt solutions at the concentration in which none of the marked radicles would survive at the end of twenty-four hours. A few experiments, however, showed that this was not the proper method, for occasionally one of the rootlets would be sound and healthy at the end of twenty-four hours in a concentration far above that which would permit the roots of a majority of the plants to survive. In other words, individual variation plays such an important part that the strength of a solution which would permit no root tips to survive would be far above that representing the limit of endurance for the variety as a whole. Attention is thus once more directed to the fact that results obtained from a few individuals are as a rule very inaccurate and unreliable. The characters of a variety (and resistance to toxic effects is one of its characters) are the mean of those of the whole number of individuals composing it. Of course all the individuals of a variety can not be examined, but the number of seedlings experimented with should be large enough to overcome the effect of marked individual variation. It was this consideration that urged the writer to make such a large number of tests. On the other hand, a concentration which would just permit all root tips to survive would not represent the general limit for the variety because of those few individuals which are far inferior to the average in their ability to resist toxic salt solutions. The limit of endurance for the mean of the largest possible number of individuals is the end sought.

After consideration, it seemed that the most perfect idea of the limit for each variety could be obtained by taking the concentration in which about half the seeds survived and about half died. For instance, if 60 seeds were tested in a 0.01 normal solution of magnesium sulphate and 30 survived and 30 died, the toxic limit would be represented by that concentration. Of course it was seldom possible to secure such an equal division, but a slight excess one way or the other would not materially alter the results. In practice it was, furthermore, often found expedient to take the mean of the concentrations actually tested as representing the toxic limit.

To illustrate: The roots were often found dead in a 0.01 normal solution of magnesium chlorid, and alive in a 0.0075 normal. The approximate toxic limit was fixed at the concentration intermediate between these two, although no solutions intermediate in concentration between 0.01 and 0.0075 of a normal solution were actually made up.

The writer does not claim that the limits thus fixed are absolute, but he believes that further experiments would change them very little. To obtain absolutely exact results it would be necessary to employ an indefinite number of solutions of intermediate concentration, and to make tests with a very large number of seedlings. The results recorded here, it is safe to assume, will answer all practical purposes. The different strengths of solution of the same salt differed from each other by 0.005 of a normal solution for sodium chlorid, sodium sulphate, and sodium bicarbonate, and by 0.0025 of a normal solution for sodium carbonate, magnesium sulphate, and magnesium chlorid. That is to say, experiments were made with solutions of a concentration of 0.015, 0.01, 0.005, etc., for sodium chlorid, sodium sulphate, and sodium bicarbonate, and of a concentration of 0.01, 0.0075, 0.0025, etc., for magnesium chlorid., magnesium sulphate, and sodium carbonate, intermediate concentrations being disregarded in practice.

As mentioned earlier in this paper, the death point was determined largely by the elongation of the roots beyond the point 15 mm. from the tip, marked off by india ink. If the roots showed no additional elongation the second 24 hours in hydrant water, they were considered dead. In some cases, however, it has been possible to determine this point by other means.

In the case of the two magnesium salts a solution of a concentration considerably above the limit blackens about 1 or 2 millimeters of the root tip, and often causes the end of the root to bend in the shape of a hook. An appearance of this kind is conclusive evidence that the solution is much too concentrated. Both sodium carbonate and sodium bicarbonate in very strong solution cause a yellowing of the whole body of the root in the solution, and more or less loss of turgor, due, doubtless, to plasmolysis. It is very seldom that rootlets which show that condition at the end of twenty-four hours in the solution will revive when placed in hydrant water.

To make the results herein contained exactly comparable with those furnished by Kearney and Cameron from their studies on lupines, the toxic limits are given in this paper both in fractions of a normal solution and in parts of salt per 100,000 of solution. In addition, the mean of the limits of all the varieties is given under each salt, so that a glance will show how much above or below this point any particular variety may be in regard to each salt used.

The salts have been found harmful in pure solutions in about the order in which they follow each other in the succeeding part of this report—that is, sodium sulphate is less harmful than sodium chlorid when both are in equivalent concentration, and magnesium sulphate is more harmful than sodium bicarbonate when in the same proportion. A concentration of 0.0075 normal magnesium sulphate usually produces about the same effect as 0.025 sodium bicarbonate. Therefore one would say that magnesium sulphate is three times as injurious as sodium bicarbonate when in equivalent concentration.

RESULTS OF EXPERIMENTS.

RESULTS WITH MAGNESIUM SULPHATE.

The results obtained for the different varieties with pure solutions of magnesium sulphate are shown by the following table:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional part of a normal solution.
Zimmerman	42	0.0075
Kharkof	25	.00625
Padui	42	.0075
Kubanka	42	.0075
Turkey	56	.01
Maraouani	42	.0075
Budapest	56	.01
Preston	28	.005
Chul	28	.005
Average for all varieties	40	.00736

A glance at the above table is sufficient to show the considerable difference between the varieties in their ability to resist the toxic influence of magnesium sulphate. The least resistant of all the varieties are Chul and Preston, of which about half the seedlings survived in a 0.005 normal solution. Contrasted to these are the two most resistant ones, viz, Budapest and Turkey, surviving equally well in a solution twice as concentrated.

A comparison of these results with wheat with those obtained by Kearney and Cameron using *Lupinus albus* with the same salt will show the great diversity between these two plants. The toxic limit for lupines in a pure solution was found to be 0.00125 of a normal solution. Accepting the results shown by these figures, magnesium sulphate is four times as toxic to lupines as it is to the Chul and Preston wheats, and eight times as toxic as for the Budapest and Turkey varieties. It may be said in this connection that from experiments made by Kearney[a] with maize there is reason to believe that the Gramineae as a family are much less sensitive to the effect of magnesium salts than the Leguminosae. Magnesium sulphate has been found in the course of these experiments with wheat to be on an average much the most toxic of the salts used. It was the most injurious in every case except in two instances, in one of which sodium carbonate and in the other magnesium chlorid proved more toxic. It required a solution of magnesium sulphate twice as concentrated as that of sodium carbonate to be equally toxic to the Budapest variety, the limits in this case being 0.01 normal magnesium sulphate and 0.005 normal sodium carbonate. The other instance referred to is not so marked. Magnesium chlorid is found to be somewhat more toxic than magnesium sulphate for one variety—Turkey—the limits being for magnesium chlorid 0.0075 normal and for magnesium sulphate 0.01 normal.

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[a] Science, N. S., 17: 386 (1903).

Comparing the average toxic limit for each salt, as stated in the tables that follow, magnesium sulphate is one and two-sevenths times as injurious as magnesium chlorid, one and three-sevenths times as injurious as sodium carbonate, three and five-sevenths times as injurious as sodium bicarbonate, little more than six times as toxic as sodium sulphate, and seven and five-sevenths times as injurious as sodium chlorid.

Magnesium sulphate in the soil is not considered injurious to any appreciable extent, but this is no doubt due to the neutralizing effect of other salts with which it is associated. Kearney and Cameron, in their experiments on *Lupinus albus* and *Medicago sativa*, found magnesium sulphate in pure solutions to be the most toxic of all the salts. The writer found the same true for the lupines. But when other salts are added to a solution of magnesium sulphate, toxicity, both absolute and relative, is altered. Kearney and Cameron[a] say:

> Addition of sodium sulphate, which itself is injurious in pure solution, raises the limit of magnesium sulphate three times, while the presence of calcium sulphate allows a small proportion of the roots to barely survive during twenty-four hours in a solution of magnesium sulphate 480 times as concentrated as that which in pure solutions represents the limits of endurance.

To lower classes of plant life magnesium sulphate is apparently much less toxic. Dr. B. M. Duggar[b] has made some experiments with marine algæ to determine the nutrient value of the salts of some of the alkalis and alkali earths when added to sea water. He found that after the acids and some of the salts of the heavy metals the potassium phosphates proved most toxic. The least toxic were the salts of sodium and magnesium, while the sulphate of magnesium was the least injurious of all the salts used. The less injurious effect of the magnesium salts is probably due to the presence of neutralizing salts in the sea water to which he added the magnesium compounds, although we are not yet in a position to say that magnesium may not be far less toxic to the Algæ than to the Leguminosæ or Gramineæ.

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[a] Some Mutual Relations Between Alkali Soils and Vegetation. Report No. 71, U. S. Department of Agriculture (1902).

[b] The Toxic Effect of Some Nutrient Salts on Certain Marine Algæ. Science, N. S., 17: 459 (1903).

To show the relative toxic effect of magnesium sulphate to some of the other salts, Loew [a] has made some interesting observations, and states that Spirogyra died within four or five days in a 1-per-mille solution of magnesium sulphate, but remained alive for a long time in corresponding solutions of the sulphates of sodium, potassium, and calcium. Upon the roots of some higher plants the same investigator made similar observations, and says that Vicia and Pisum do not start lateral roots when kept in a solution of 0.5 per cent of magnesium sulphate or nitrate, and the root cap and epidermal cells die after a few days. Seedlings of Phaseolus placed in a solution of 0.1 per cent magnesium sulphate with 0.1 per cent of monopotassium phosphate showed injury to the roots after five days, and the entire plant succumbed soon afterwards.

Coupin [b] found during the course of some experiments with wheat that magnesium chlorid was more toxic than magnesium sulphate. He gives the limit for magnesium sulphate at 1 per cent and for magnesium chlorid at 0.8 per cent.

RESULTS WITH MAGNESIUM CHLORID.

The following table shows the results obtained for the different varieties with pure solutions of magnesium chlorid:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional part of a normal solution.
Zimmerman	72	0.015
Kharkof	48	.01
Padui	48	.01
Kubanka	42	.00875
Turkey	36	.0075
Maraouani	48	.01
Budapest	60	.0125
Preston	24	.005
Chul	24	.005
Average for all varieties	40	.00831

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[a] The Physiological Rôle of Mineral Nutrients in Plants. Bul. 45, Bureau of Plant Industry, U. S. Department of Agriculture (1903).

[b] Sur la Toxicité du Chlorure de Sodium et de l'Eau de Mer a l'Egard des Végétaux. Revue Générale de Botanique, 10: 188 (1898).

Magnesium chlorid, like the sulphate, seldom occurs alone in nature in sufficient quantity to be of very great consequence. It is nearly, if not always, associated in the soil with some other salts, such as those of sodium and calcium, which tend to neutralize its effect upon plants. In these experiments with wheat, as in those with lupines, it was found to rank next to magnesium sulphate as a toxic agent when in pure solutions.

The average limit of concentration of magnesium chlorid for wheat seedlings is 0.00931 of a normal solution, as against 0.00736 for magnesium sulphate. Again, referring to Kearney and Cameron's results with the same salts for lupines, we find some variations. As is easily seen with the writer's results with wheat, magnesium sulphate is only about one-third more toxic than magnesium chlorid, while Kearney and Cameron's results show the sulphate twice as toxic as the chlorid. The investigators named found the roots of lupines to barely survive in 0.0025 of a normal solution of magnesium chlorid, while Kearney showed that *Zea mays* would live in a solution a little more than thirty times as concentrated. Magnesium chlorid is twice as toxic to the white lupine as to the least resistant variety of wheat tested, and six times as toxic to the lupine as to the most resistant variety of wheat. It is a surprising fact that some varieties of wheat are six times as resistant and that maize is thirty times as resistant to this salt as *Lupinus albus*.

It will be seen that the variation of the wheat varieties among themselves is more pronounced in the chlorid than in the sulphate. While the toxic limit for the least resistant of the varieties is the same (0.005 of a normal solution) for the two salts, that of the most resistant variety (0.015 normal) is much higher in magnesium chlorid than in the sulphate. The ratio of variation between the two extremes of resistance with magnesium sulphate was 2 to 1, as against 3 to 1 with the chlorid.

RESULTS WITH SODIUM CARBONATE.

The following table gives the results with pure solutions of sodium carbonate:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional part of a normal solution.
Zimmerman	65	0.0125
Kharkof	78	.015
Padui	52	.01
Kubanka	39	.0075
Turkey	78	.015
Maraouani	41	.008
Budapest	26	.005
Preston	65	.0125
Chul	65	.0125
Average for all varieties	57	.0109

The results shown by the above table are not materially different from those with magnesium chlorid. Sodium carbonate in pure solutions is slightly less harmful, as shown by the comparison of the average of all the varieties, being in the case of magnesium chlorid 0.0093 and for sodium carbonate 0.0109 of a normal solution. The extremes in both cases are the same, though there are two varieties with a resistance of 0.015 for sodium carbonate as against one for magnesium chlorid. Five varieties in the case of sodium carbonate have a resistance above the average as against four in the case of magnesium chlorid. One variety alone, Budapest, has a resistance of only 0.005 as against two for magnesium chlorid.

Of the three salts so far described, sodium carbonate is in the soil generally the most harmful, (1) because in excessive quantity it is more widely distributed, and (2) because it is less easily neutralized by other salts with which it is usually associated.

The opinions of experimenters differ considerably as to the relative toxic effect of this salt. Kearney and Cameron showed that, in the case of *Lupinus albus* at least, sodium carbonate is but little more injurious than sodium sulphate, the toxic limit in each case being 0.005 and 0.0075 of a normal solution, respectively. It will be seen that the limit for the lupine obtained by them with sodium carbonate is the same as the resistance for Budapest wheat, but only one-third of that for the Turkey and Kharkof varieties. The limit of concentration for the lupine, as shown by their report, is about equivalent to one-half of the average for the several wheat varieties in the same salt solution. Kearney found *Zea mays* to survive in the same salt at a concentration three times as great as that representing the limit for the lupine, and equal to that for the most resistant varieties of wheat.

Coupin[a] found the toxic limit of wheat in sodium carbonate to be about 1.1 per cent. In view of the fact, however, that he noted the death of the whole plant and not the root tips, the limit of concentration as determined by him would necessarily be much higher.

RESULTS WITH SODIUM BICARBONATE.

The limits in pure solutions of sodium bicarbonate are shown in the following table:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional parts of a normal solution.
Zimmerman	234	0.028
Kharkof	251	.03
Padui	230	.0275
Kubanka	209	.025
Turkey	230	.0275
Maraouani	188	.0225
Budapest	209	.025
Preston	209	.025
Chul	209	.025
Average for all varieties	219	.026

Of all the salts used sodium bicarbonate seems to bring out the least variation in resistance so far as these experiments are concerned. The least resistant variety was Maraouani and the most resistant Kharkof, which were able to survive in a 0.0225 and 0.03 normal solution, respectively. These results do not differ to an important extent from those of Kearney and Cameron for *Lupinus albus*, the toxic limit of which was slightly lower (0.02) than that for Maraouani wheat.

The writer finds sodium carbonate to be about two and six-tenths times as injurious to wheat when in equivalent concentration as sodium bicarbonate. Kearney found the difference to be even greater in the case of maize, the ratio being about 4 to 1. Coupin[b] reverses the relative toxic order of these two salts. This difference in the criterion of toxic action, i. e., the death of the whole plant rather than of the root tip alone, should not affect the relative toxic influence of the two salts. Coupin's results showed that it required a 1.1 per cent solution of sodium carbonate to kill wheat seedlings, while only 0.6 per cent was necessary to produce the same effect when sodium bicarbonate was employed.

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[a] Sur la Toxicité du Chlorure de Sodium et de l'Eau de Mer a l'Egard des Végétaux. Revue Générale de Botanique, 10:180 (1898).

[b] Sur la Toxicité des Composés de Potassium et de l'Ammonium a l'Egard des Végétaux Supérieurs. Revue Générale de Botanique, 12:180 (1900).

As to the relative toxic order of the carbonate and bicarbonate, the results recorded agree quite well with those of Sigmund,[a] who found that wheat development was retarded and germinating seeds of vetch and rape were killed in a 0.5 per cent solution of sodium carbonate, while the same concentration of sodium bicarbonate was quite harmless.

Kearney and Cameron found sodium bicarbonate somewhat less toxic than sodium chlorid for the lupine, and, further, that a 0.02 normal solution of sodium bicarbonate permits plants to survive in much better condition than in the corresponding concentration of the chlorid. Kearney has also shown by experiments that the bicarbonate is less toxic to maize than is sodium chlorid, the death point for the bicarbonate being established at 0.05 and for the chlorid at 0.04 of a normal solution.

In view of all these differences it will be no easy matter to decide the relative harmfulness of these sodium salts. Experiments will have to be performed on a large number of plants of widely different relationship before any definite conclusions can be reached. There is great probability that the order of their toxicity is not the same for all species of plants. This is very well demonstrated by a comparison of the writer's results with those of Kearney and Cameron, who found sodium sulphate more toxic to *Lupinus albus* than sodium bicarbonate, while the writer found the reverse to be true for wheat. There is a tendency among physiological experimenters to draw general conclusions for the whole plant kingdom from the results obtained for a few varieties, species, or genera, which is absolutely unjustifiable. Too much emphasis can not be used in condemning such inferences. The results here obtained, it is thought, will hold good for these particular varieties of wheat, but they are not indicative except within rather wide limits of what others show.[b] They will serve for making comparisons, but not for drawing conclusions as to the behavior of plants in general.

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[a] Ueber die Einwirkung Chemischer Agentien auf die Keimung. Landw. Vers. Stat., 47: 2 (1896).

[b] This point is brought out in a most marked way by the work of Cameron and Breazeale upon the effect of acids on wheat, maize, and clover, respectively. (The Toxic Action of Acids and Salts on Seedlings. Journal Phys. Chem., vol. 8, No. 1, p. 1, Jan., 1904.)

RESULTS WITH SODIUM SULPHATE.

The comparative effect of pure solutions of sodium sulphate upon the different varieties is shown in the table which follows:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional parts of a normal solution.
Zimmerman	353	0.05
Kharkof	300	.0425
Padui	318	.045
Kubanka	353	.05
Turkey	300	.0425
Maraouani	336	.0475
Budapest	265	.0375
Preston	242	.035
Chul	283	.04
Average for all varieties	305	.0433

In sodium sulphate, as in sodium bicarbonate, the toxic limits for the different varieties show less variation than in the case of other salts used. The least resistant to this comparatively harmless salt, as to most of the others used in these experiments, is the Preston wheat. This variety has been grown for a number of years in a semihumid region where alkali soils do not occur. In view of these facts one would expect this variety to be somewhat less resistant to these salts. Since there is no excess of soluble salts in the soils of this region, Preston has had no opportunity to develop salt resistance. The varieties most resistant to sodium sulphate are Zimmerman and Kubanka, both surviving as well in a 0.05 normal solution as Preston in 0.035. As to the origin of these varieties, also, it is just what would be expected from their resistance to salts. Both sorts came from arid or semiarid regions, where saline soils are abundant. Kubanka is grown in regions containing numerous salt marshes and lakes, and that it should have acquired ability to resist salts in the soil is only natural. Zimmerman likewise was obtained from a region having soils of more or less saline character, and to this is probably due its power of resistance in salt solutions. It is not unlikely that the soils from the regions from which the remaining varieties were obtained contain a less amount of sodium sulphate proportionate to their smaller resistance to this salt as shown in these water cultures. This can not definitely be known until experiments have been made correlating the amount of the different salts in the soil upon which the different varieties grew, with their resistance in pure solutions.

Some interesting differences can be noted here between the resistance of wheat and of lupines to sodium sulphate. The Preston variety is 4⅔ times as resistant, and Zimmerman and Kubanka 6⅔ times as resistant, as *Lupinus albus*, the toxic limit of the latter having been established by Kearney and Cameron at 0.0075. They found sodium sulphate more toxic to Lupinus than sodium bicarbonate, while for every variety of wheat in these experiments the reverse is true. With maize Kearney showed that the seedling would survive equally well in both salts, and established the limit at 0.05 of a normal solution.

Hilgard states that few plants can bear as much as 0.1 per cent in the soil of sodium carbonate, or about 3,500 pounds per acre to the depth of 1 foot. For sodium chlorid the limit in the soil is about 0.25 per cent. In the case of sodium sulphate, most plants can grow in the presence of 0.45 to 0.50 per cent in the soil. In view of this fact sodium chlorid under soil conditions would seem to be more toxic to most plants than the sulphate.

Stewart[a] has made a number of interesting tests on the power of seeds to germinate in the presence of sodium carbonate, sodium sulphate, and sodium chlorid. He found the carbonate and the chlorid to be more injurious than the sulphate. With one exception (rye seeds in the presence of the chlorid), 0.50 per cent of either carbonate or chlorid proved fatal to germination. Stewart showed that sodium sulphate is far less injurious than either of the other salts. The character of his experiments indicates, however, that they are not directly comparable with such as are here described. His seeds were placed for germination in sand on tin plates and watered, the nature of the water used not being stated. Kearney and Cameron have shown that these salts are decidedly different in the degree to which their toxic effect can be neutralized by the addition of other salts, such as the chlorid or sulphate of calcium. It is possible that the sand or the water, or both, used by Stewart contained more or less calcium salts. The results of Kearney and Cameron, above referred to, show that the toxic effect of sodium carbonate, and next to it that of sodium chlorid, are neutralized far less effectively by calcium sulphate than is sodium sulphate. They found that the resistance of sodium sulphate was raised 60 times by adding calcium sulphate. In the light of these facts it is easy to accept Stewart's results. In fact, Kearney and Cameron showed that when other salts were added the limit for *Lupinus albus* in sodium sulphate could be raised to 0.30 of a normal solution, and that for sodium chlorid only to 0.20, while in pure solutions the limit for sodium sulphate was a concentration of 0.0075 and for sodium chlorid 0.02. This also explains Hilgard's results as to the comparative harmlessness of sodium sulphate in the soil where other salts are always present.

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[a] Effect of Alkali on Seed Germination. Ninth Annual Report, Utah Agricultural Experiment Station, p. 26 (1898).

RESULTS WITH SODIUM CHLORID.

The results obtained by the writer with pure solutions of sodium chlorid are shown in the following table:

Name of wheat variety.	Maximum limit of endurance.	
	Parts per 100,000 of solution.	Fractional part of a normal solution.
Zimmerman	377	0.065
Kharkof	319	.055
Padui	333	.0575
Kubanka	333	.0575
Turkey	290	.05
Maraouani	319	.055
Budapest	275	.0475
Preston	319	.055
Chul	261	.045
Average for all varieties	314	.0542

That sodium chlorid is the least toxic to wheat of all the salts used is evinced by the table above. Next to it, of course, is sodium sulphate. Comparing the results with those obtained by Kearney and Cameron for lupines, the varieties of wheat are two and one-half to three times as resistant. Coupin[a] also found wheat more resistant to sodium chlorid than the white lupines. He has experimented with several species of plants and found the whole plant to be killed in the following concentrations: Wheat, 1.8 per cent; peas, 1.2 per cent; vetch, 1.1 per cent; maize, 1.4 per cent, and white lupine, 1.2 per cent.[a]

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[a] Sur la Toxicité du Chlorure Sodium et de l'Eau de Mer a l'Egard des Végétaux. Revue Générale de Botanique, 10:178 (1898).

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[a] Guthrie, F. B., and Holmes, R. (Roy. Soc. New South Wales, Oct. 8, 1902), conducted some experiments on wheats in two kinds of soils. To one of the soils was added a fertilizer consisting of a mixture of 15 grams of sulphate of ammonia, 6 grams of superphosphate, 4 grams of sulphate of potash, and varying quantities of other substances. The composition of the first soil was as follows:

	Per cent.
Moisture	3.83
Organic matter	13.75
Nitrogen	.208
Soluble in hydrochloric acid:	
Lime	.165
Potash	.065
Phosphoric acid	.107
Magnesia	.072

The soil was found to contain 0.016 per cent of sodium chlorid in addition to the substances enumerated above.

The composition of the second soil was as follows:

	Per cent.
Moisture	2.91
Organic matter	8.33
Nitrogen	.070
Soluble in hydrochloric acid:	
Lime	.440
Potash	.077
Phosphoric acid	.110

No fertilizer was added and the soil was originally free from chlorids. It was found that in the first soil the seeds germinated and grew well when enough sodium chlorid was added to the soil to give it a content of 0.066 per cent of that salt. Further, that in the second soil, to which no fertilizer was added, in the presence of 0.05 per cent of sodium chlorid, germination was slightly retarded, but the plants finally recovered and grew well. As to the results, these authors say:

> From 0.01 to 0.02 per cent of sodium chlorid is without effect on the wheat plant, the grain germinating well and the plant growing vigorously. With 0.05 to 0.10 per cent of sodium chlorid the germination is somewhat retarded, the plants are less vigorous, but recover and grow well. With 0.15 the germination is still more affected and the plants would probably not recover under less favorable conditions than those of the experiment. Two-tenths per cent of sodium chlorid in the soil is fatal to the growth of wheat.

An experiment performed by Messrs. E. Charabot and A. Hébert (Compt. Rend. Acad. Sci. Paris, 134: 181, 1902), which shows the chemical influence of sodium chlorid upon more mature plants, is a very interesting one. These investigators found that by adding sodium chlorid some chemical properties are decreased.

The writer finds that a 2 per cent solution of sodium chlorid saturated with calcium sulphate is sufficient to kill moss growing on the soil in two weeks' time. At the end of one week no change is noticeable, except that growth is retarded. One week longer, however, suffices to kill the moss completely and turn it a brownish color. The solution was added to the pots on which the moss grew in the laboratory every other day for about that length of time.

SUMMARY OF TABLES.

In order to make more easily comparable the differences of resistance of the several varieties to the various salts, the results as a whole have been brought together in the following table. At the bottom of the columns is given the average, for each salt, of the toxic limits of all the varieties; so it requires only a glance to see which varieties are above or below the average in their resistance to the toxic effect of each salt.

Name of wheat variety.	Magnesium sulphate.	Magnesium chlorid.	Sodium carbonate.	Sodium bicarbonate.	Sodium sulphate.	Sodium chlorid.
Zimmerman	0.0075	0.015	0.0125	0.028	0.05	0.065
Kharkof	.00625	.01	.015	.03	.0425	.055
Padui	.0075	.01	.01	.0275	.045	.0575
Kubanka	.0075	.00875	.0075	.025	.05	.0575
Turkey	.01	.0075	.015	.0275	.0425	.05
Maraouani	.0075	.01	.008	.0225	.0475	.055
Budapest	.01	.0125	.005	.025	.0375	.0475
Preston	.005	.005	.0125	.025	.035	.055
Chul	.005	.005	.0125	.025	.04	.045
Average	.00736	.0093	.0109	.026	.0433	.0542

A glance at the above table shows that the Zimmerman variety is much the most resistant. This, however, does not necessarily mean that it is most resistant to every salt. On the contrary, Zimmerman is less resistant to magnesium sulphate than Budapest and Turkey, less resistant to sodium carbonate than Turkey and Kharkof, and less resistant to sodium bicarbonate than Kharkof. This same variety, however, is very resistant to the influence of sodium chlorid, sodium sulphate, and sodium carbonate, which brings up its average to a considerable extent. The least resistant variety is Chul, which runs low for all salts except sodium carbonate, in which its resistance is slightly above the average of the varieties with which experiments were made. The low resistance of this variety was unexpected, in view of the character of the country from which it came.

A further consideration of this table shows how nearly equal the Padui and Kubanka varieties are in their resistance. A comparison of the two varieties for the same salts shows but a slight variation. Taking into consideration the original habitat of the two varieties, we would expect very little difference. Both are Russian varieties and subjected to very similar climatic and soil conditions. Both varieties are very resistant to salt solutions, and in view of the fact that they both come from regions containing much saline soil their similarity in this respect is not surprising.

Good examples for contrast to Padui and Kubanka are furnished in Budapest and Preston. Budapest is a naturalized Michigan variety and Preston a variety from Canada. The soil and climatic conditions are very similar. Both regions are comparatively humid, with little or no saline soil. Both of these varieties are low in resistance to salt solutions, just as would be expected.

A comparison of the resistance of the different varieties with the region from which they came in respect to soil and climatic conditions shows that their resistance to saline solutions can probably be correlated with the natural habitat of the varieties; that is, the results herein obtained indicate that a variety grown in a locality having little or no excess of salts in the soil has a comparatively low resistance in saline water cultures. It further shows that varieties grown in regions having more saline soils have a much greater resistance in saline water cultures.

COMPARISON OF RESULTS WITH DIFFERENT SPECIES.

The results obtained for the lupines by Kearney and Cameron and those for maize by Kearney have frequently been referred to in the foregoing pages. It has been possible to compare them to the writer's results with wheat only in a fragmentary way. Since there are some very surprising differences in the toxicity of the same salts to the three plants, the results have been brought together in one table for comparison. Kearney and Cameron used but one variety of the lupine and of maize, their results being shown in the following table. The writer in his experiments on wheat has used nine different varieties, but in the following table only the mean resistance of all the varieties has been taken.

The limit of concentration of the salts which can be endured by wheat, lupine, and maize is as follows, the results being stated both in fractions of a normal solution and in parts of salt per 100,000 of solution:

Salt.	Degree of concentration.					
	Wheat.		Lupine.		Maize.	
	Parts of a normal solution.	Parts per 100,000 of solution.	Parts of a normal solution.	Parts per 100,000 of solution.	Parts of a normal solution.	Parts per 100,000 of solution.
Magnesium sulphate	0.007	39	0.00125	7	0.25	1,400
Magnesium chlorid	.009	108	.0025	12	.08	384
Sodium carbonate	.01	52	.005	26	.015	78
Sodium bicarbonate	.026	217	.02	167	.05	417
Sodium sulphate	.043	302	.0075	53	.05	353
Sodium chlorid	.054	313	.02	116	.04	232

It is remarkable that while magnesium sulphate is the most toxic to the wheat and the lupine of all the salts used it is the least injurious to maize, being thirty-five times and two hundred times, respectively, more toxic to wheat or lupine than to maize.

Magnesium sulphate and magnesium chlorid differ but little in the concentration necessary to kill the root tips of wheat seedlings, while a solution of the former only half as strong as the latter is sufficient to kill the lupines in the same length of time. In contrast to this, a solution of magnesium chlorid only about one-third as concentrated as the critical solution of magnesium sulphate is the strongest that can be endured by the root tips of maize, the order of toxicity of the two salts being reversed. The root tips of the lupines have been killed by every salt used, at a less concentration than that which can be endured by wheat and maize, a solution of sodium carbonate one-half and one-third as concentrated as that necessary to kill wheat and maize, respectively, being fatal to the lupine. It will be noticed, however, that the least amount of diversity is evinced by the three plants in the presence of sodium carbonate and sodium bicarbonate.

Wheat and maize show very little difference in resistance to sodium sulphate, but a solution about one-sixth as concentrated as that necessary to kill maize is toxic to the lupine.

It is a very surprising fact that the variation between the three plants is so great. The salts of magnesium which are the most toxic to wheat and lupines are the least toxic to maize, the difference being as is 200 to 1. Maize is on the whole much more resistant to pure salt solutions than is wheat or the white lupine, while the root tips of the lupines are killed by each of the salts at a much less concentration than that necessary to destroy the root tips of wheat seedlings.

Especially interesting results in this connection have been brought out by Cameron and Breazeale[a] with some experiments concerning the action of acids and salts upon maize, wheat, and clover. The salts employed were not the same as those used by the writer, but the results for both the acids and salts are sufficient to show the difference in resistance between different species and also the different action of different salts and acids on the same species.

Cameron and Breazeale found that N 850 and N 600 solutions of acetic and succinic acids, respectively, were the toxic limit for seedlings of maize, but wheat and clover in the same acids would endure only N 20000. They found the variations in salt solutions to be equally as great, but in some ways reversed. In potassium chlorid the toxic limit for wheat and clover is the same, each having a greater concentration than that necessary to kill seedlings of maize. In potassium oxalate, wheat was found to endure a concentration six times as great as that for clover. It is interesting to note here that the more toxic the acids the more uniform are the results, while for the salt solutions the reverse is true. The writer obtained similar results for the salts used in the experiments described in this paper.

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[a] The Toxic Action of Acids and Salts on Seedlings, Journal Phys. Chem., vol. 8, No. 1, p. 1 (January, 1904).

ASH ANALYSES.

To determine whether or not the amount or the composition of the ash in the seed could be correlated with the resistance of the seedlings to saline solutions, analyses of seeds of each variety used and of the same origin as those used in the culture experiments were obtained through the Bureau of Chemistry of the Department of Agriculture. The results fail to show any correlation between the ash constituents of the seeds and the resistance of the seedlings in water cultures. As the absence of such correlation is important, the table of analyses is inserted. It is a surprising fact that some of the ash constituents run very low for varieties such as Padui and Kharkof, in which one would expect them to be high.

Table of analyses of the ash constituents of wheat seedlings.

Variety.	H_2O.	Crude ash.	CO_2.	MgO.	K_2O.	Na_2O.	P_2O_5.	SO_3.	Cl.
Zimmerman	8.34	1.72	0.080	0.22	0.45	0.050	0.85	0.037	0.054
Kharkof	8.25	1.35	.066	.18	.41	.050	.56	.040	.054
Padui	8.72	1.40	.048	.18	.43	.052	.57	.040	.042
Kubanka	7.68	1.93	.064	.22	.53	.056	.93	.043	.054
Turkey	7.54	1.73	.064	.20	.51	.046	.78	.041	.054
Maraouani	9.70	1.66	.028	.15	.51	--------	.70	.043	.054
Budapest	8.38	1.91	.048	.21	.53	.042	.94	.040	.054
Preston	8.48	1.35	.040	.23	.47	.045	.97	.057	.054
Chul	7.78	1.98	.088	.28	.50	--------	.78	.042	.054

INDIVIDUAL VARIABILITY.

Individual variation within the different varieties is a subject deserving some attention in this connection. Some very striking instances have been noted during the course of these experiments. Since it has been demonstrated beyond dispute that the varieties differ one from another in resistance to toxic salts, it is only natural to suppose that the individuals of the same variety would show diversity in this respect. It is the existence of this individual variability that has made it impossible to obtain reliable results without testing a large number of seedlings. As soon as this factor was eliminated it became comparatively easy to establish the toxic limit. In some instances it was more difficult than in others, and some varieties were especially troublesome in this respect. The reasons for this are difficult to determine.

No experiments have been conducted for the exclusive purpose of demonstrating the range of individual variation, and only results are here recorded which have been brought out incidentally during the tests for varietal variation. The writer does not doubt that experiments with this end in view would bring out instances of individual variability much more striking than any so far obtained. Nearly all varieties, however, have shown exceeding diversity in the resistance of individual plants, and it will be interesting to mention a few of them. In the experiments to determine the toxic limits for the different varieties the results were based on averages, e. g., in a solution of sodium carbonate of a concentration that was taken to represent the toxic limit 23 seeds were alive in a 0.01 solution and 27 dead. It is not known how many of those seedlings which were alive might have survived in a solution still more concentrated, perhaps of twice the strength, nor is it known how many of those that were killed would have been killed in a solution only half as concentrated.[a]

Instead of making tables to show the individual variation, as was first suggested, only striking instances will be referred to under the names of the different varieties. A series of tables would require more space than can here be given to the subject.

Budapest.—In connection with the experiments with the Budapest variety two striking instances have been noted, one with sodium bicarbonate and the other with magnesium sulphate. The toxic limits for these two salts are 0.025 and 0.01 of a normal solution, respectively. In one experiment, out of a number of seedlings in 0.015 normal sodium bicarbonate two died. In the case of magnesium sulphate, in one experiment all the rootlets were dead in 0.015 normal except one, which survived. Here are two instances with remarkable extremes. In the former case the two seeds were of exceedingly low vitality, while in the latter instance one seed had remarkably great vitality.

Chul.—No very marked individual variations presented themselves during the experiments with the Chul variety.

Turkey.—Few remarkable variations were observed with the Turkey variety. But one instance deserves special attention. The average toxic limit in magnesium sulphate is 0.01 normal, but in a number of tests a few seedlings were readily killed in a solution only half as concentrated as the solution in which one-half of the total number of individuals exposed to it survived.

Preston.—The experiments with magnesium salts brought out two interesting cases with the Preston variety. The toxic limit for this variety with both the chlorid and the sulphate of magnesium is 0.005 normal. In both salts, however, rootlets of some of the plants survived in solutions twice as concentrated. In the case of magnesium chlorid, 8 out of 25 survived, while with the sulphate only 2 out of the same number survived.

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[a] Moore and Kellerman (Bul. 64, Bureau of Plant Industry, U. S. Dept. of Agriculture) have given some excellent instances of individual variability with respect to resistance to toxic agents. They have made numerous experiments with copper sulphate upon different algæ which are found in water supplies. They found that 1 part of copper sulphate to 2,000 of water was sufficient to kill one-half of the individuals of *Chlamydomonas piriformis* exposed to it in two days, while the same concentration was sufficient to kill only one-tenth of the same form in three following days, and in three other days only one-fourth. With *Desmidium swartzii* 1 pa:t of copper to 100,000 was sufficient to destroy one-half and three-fourths, respectively, of the individuals involved in two different sets of experiments. Numerous other instances might be cited, but these will suffice to show that individual variation in this respect is not confined to wheat alone.

Kharkof.—In solutions of sodium chlorid and sodium sulphate of a concentration of 0.045 and 0.035 normal, respectively, one seedling of the Kharkof variety was dead in each, the limits fixed for these two salts being 0.055 and 0.0425. The root tips of two seedlings were killed in 0.02 normal of sodium bicarbonate, for which the average toxic limit is 0.03.

Zimmerman.—The Zimmerman variety, while the most resistant of all, shows some very marked individual variation. A striking instance occurred with magnesium chlorid, the average toxic limit of which is 0.015 normal. In a solution one-third as concentrated (0.005 normal) 2 seedlings out of 20 could not survive. The limit of concentration for this variety in sodium chlorid is 0.065 normal, but the rootlets of one seedling could not survive in 0.045. Similar to this are the results with sodium sulphate, the toxic limit being 0.05, but the root tips of two individuals did not survive in 0.035 normal solution.

Padui.—No variation of any importance.

Maraouani.—The rootlets of two seedlings of the Maraouani variety were killed in 0.005 normal magnesium sulphate, while 3 out of 20 individuals survived in 0.015. The average toxic limit for this salt is 0.0075 of a normal solution.

Kubanka.—No important variations.

NEUTRALIZING EFFECT OF THE SALTS EMPLOYED UPON OTHER TOXIC SUBSTANCES.

Because of a discovery which was made when these experiments were almost completed it is necessary to add a few remarks upon the neutralizing effect upon other toxic substances of the salts of sodium and magnesium. During the whole course of the experiments the writer was unable to get seedlings to grow or even to live for twenty-four hours in the distilled water used. This seemed unaccountable, as it quite disagreed with the results of other experimenters. Coupin found the roots of wheat seedlings to thrive well in perfectly distilled water, and Dehérain and Demoussy[a] showed absolutely pure water to be perfectly harmless to root growth. Numerous experiments have been made to determine this point, with more or less varying results. Certain experimenters have held that distilled water was not conducive to good growth.

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[a] Sur la Germination dans l'Eau Distillé, Compt. Rend., Paris, 132: 523 (1901).

This is probably an error so far as young seedlings are concerned. The seed contains everything necessary for the early growth of the plant, and the absence of all minerals or other nutrient compounds in the surrounding solution should produce no bad effect during the earliest stages of growth. Those who claim that distilled water is injurious will probably find, upon closer observation, that it is some injurious substance in the water which is really toxic to the roots. In the case of many plants one of the most toxic substances known is copper, and it is more than likely that it is present in much of the water which experimenters have found to be injurious. Coupin states that one part of copper to 700,000,000 of water is sufficient to retard the root growth of wheat seedlings. A mere trace of copper is sufficient to retard growth in many cases.

As a result of an analysis made in the Bureau of Chemistry of the Department of Agriculture of the distilled water used in these experiments, it was found to contain a considerable quantity of zinc, but no trace of copper. The harmful effect probably should be attributed to zinc alone. The water used in these experiments was distilled but once, and was collected in a porcelain tub as a receiver.

It was thought while the work with wheat seedlings was in progress that copper or zinc might be the cause of the injurious effects, but the writer used the water from the same still for all experiments with *Lupinus albus*, and no toxic effect of the distilled water was noticeable. Control checks with lupines were carried in both distilled and hydrant water, and no difference was found in the rate of growth. It was this observation which at the outset of the work with wheat gave the writer confidence in the quality of the distilled water. This is apparently another indication that different species of plants vary greatly in their ability to resist the influence of toxic salts. Wheats are apparently much more sensitive than lupines to pure solutions of zinc salts, although much less sensitive to pure solutions of sodium and magnesium salts.

At first thought one would conclude that since the distilled water used contained harmful substances the experiments above described are practically without value; but such is not the case, as will be seen before this discussion is completed. In order to compare closely the water used during most of the experiments with absolutely pure water, some experiments were made. To secure absolute purity in the water a new still was made of the best nonsoluble glassware, having no metal in any of its parts. The same water that had been previously used was redistilled for the purpose. The wheat seedlings were treated in every way as before. A control was also carried in Potomac River water for comparison, and each lot of seed was taken up each day and the elongation of the roots measured and recorded for four consecutive days. In the twice-distilled water they grew about as well as in hydrant water. In order to show to what extent the impurity of the water used would affect former experiments, salt solutions of a dilution far below the toxic limits, as already established, were made, using the water which was but once distilled. The results showed that the toxic element in the water was effectively neutralized by the addition of even minute quantities of any one of the salts used in the experiments. For comparison equal numbers of seeds were tested at the same time in the water distilled twice, in that distilled but once (that used throughout the above-described experiments), and in dilute salt solutions made up with the once-distilled water.

The following table embodies the results obtained with very dilute solutions of the salts, with distilled water, and with hydrant water:

Water or solution.	Elongation of roots at the end of a given time.			
	First day.	Second day.	Third day.	Fourth day.
	mm.	*mm.*	*mm.*	*mm.*
Water distilled once	2.2	2.2	2.2	2.2
Water distilled twice	11.4	26.2	33.7	36.3
Magnesium sulphate (0.001 normal)[a]	10.6	21.2	27	27.6
Magnesium chlorid (0.001 normal)[a]	16.8	30.8	37.6	38.2
Sodium carbonate (0.001 normal)[a]	11.3	14.5	16.8	17.8
Sodium bicarbonate (0.0075 normal)[a]	10.6	24	31	32.4
Sodium sulphate (0.015 normal)[a]	8.5	22	31.5	34.8
Sodium chlorid (0.015 normal)[a]	7.8	15	19	22
Hydrant water	9.4	23.8	37.4	46

[a] The mean toxic limit of all varieties of wheat tested in the presence of the salts here employed is shown as follows:

	Parts of normal solution.
Magnesium sulphate	0.00736
Magnesium chlorid	.00931
Sodium carbonate	.0109
Sodium bicarbonate	.026
Sodium sulphate	.0432
Sodium chlorid	.0542

A comparison of these figures with the table above shows that from one-third to one-tenth the concentrations of the solutions which represent the limit of endurance of the wheat varieties is sufficient to neutralize the harmful effect of the zinc present in the distilled water.

The above table shows that after an elongation of 2.2 mm. during the first day in the water distilled once no further growth took place. A comparison of that with absolutely pure water (in this case redistilled) shows that there was some element in the first water which hindered growth and which was not found in the second. This, as the chemical analysis above referred to showed, is probably zinc.

The results in the dilute salt solutions which were made up with the injurious once-distilled water showed that there was no material difference in the elongation made in them and in the checks in redistilled and hydrant water. It is not assumed that these dilute solutions were in the exact proportion that would have permitted the greatest elongation. The object was merely to show that at the concentrations used in these experiments the salts of magnesium and of sodium effectively neutralize the injurious element present in the once-distilled water. The only noticeable difference was in the case of sodium carbonate and sodium chlorid, in which the elongation was somewhat below the average in the pure-water check and in the solutions of other salts. The use of a more dilute or a more concentrated solution would doubtless have removed this difference. On the other hand, a 0.001 normal magnesium chlorid was conducive to better development than any of the others, with the single exception of hydrant water. It will be noticed that at the end of the third day there was even a slight advantage in favor of magnesium chlorid over river water.

The elongation the fourth day was but a slight increase over that at the end of the third, with the one exception of the seeds in the hydrant water. This is just what was to be expected. During these four days the seeds were compelled to live on the nutriment stored up in the endosperm. This had been practically all used up at the end of the third day; hence the cessation of growth. With hydrant water the conditions were different. Certain nutritive substances are contained in this water upon which the roots can draw when those contained in the endosperm have been exhausted.

In view of the experiments, small quantities of these sodium and magnesium salts, instead of being injurious when present in the soil, might be actually beneficial in case the soil contains very toxic substances, e. g., zinc or copper. In fact, these salts are injurious only when present in excessive quantities, as in the so-called "alkali soils" of the West.

DILUTE SOLUTIONS AS STIMULANTS.

Incidentally, throughout these experiments, evidences of stimulation in dilute solutions were obtained. This has been shown to occur by many investigators with other salts and with some acids.[a]

Kearney and Cameron, who made similar observations when experimenting with *Lupinus albus*, say:

> In the case of certain salts, when plants are exposed to pure solutions which are much too dilute to produce any toxic effect, there occurred a decidedly

---

[a] Some fungi have been known to be stimulated by the presence of small quantities of poisons. The germination of spores has likewise been hastened when in the presence of acids or salts. Townsend (Bot. Gaz., 27: 458–466, 1899) found that the germination of various seeds and spores has been stimulated by the presence of traces of ether, and (Bot. Gaz., 31: 241–264, 1901) that the presence of hydrocyanic acid for a brief period of time accelerates germination and subsequent growth.

stimulating effect upon growth, as compared with that in the distilled water control during a corresponding period. This was shown to be the case for salts of calcium, both the chlorid and the sulphate acting as stimuli.

These investigators found decisive evidence of such stimulating action with both the carbonate and the bicarbonate of sodium. Sodium sulphate and sodium chlorid gave purely negative results. Very marked results of this kind were observed by Cameron and Breazeale when working with acids. Hydrochloric, sulphuric, and nitric acids in concentrations but little below the toxic limit produced enormous stimulation, especially with wheat.

Copeland[a] shows that zinc and copper in water cultures accelerate growth when the solutions are not much more dilute than those that are distinctly toxic. Similar observations have been made by many earlier investigators.

In the experiments with wheat all the salts were found to stimulate growth except sodium chlorid and sodium carbonate, which were indifferent at the lowest concentration used. It is not unlikely, however, that if the proper dilution of the carbonate were employed it would be found to act as a stimulus with wheats just as it did with lupines. In fact, it was found that the same concentration of certain salts which was decidedly toxic for some varieties of wheat will act as a stimulant to another variety. Especially is this true of the chlorid and sulphate of magnesium. In a 0.005 solution of each of these salts the elongation of the roots of Turkey wheat was equal to that in the control of hydrant water during the period of twenty-four hours. The toxic limits for this variety are 0.0075 normal for the chlorid and 0.01 normal for the sulphate. As will be seen, two-thirds and one-half the concentration of the toxic limit, respectively, not only were not toxic but actually acted as a stimulating influence. There is a possibility, in view of these results, that dilutions not very much below the toxic limit are more likely to have a stimulating effect than are much more dilute solutions. This, however, is not a question to be settled at this time, but will require to determine it a series of special experiments.

A 0.015 normal solution of sodium sulphate caused an elongation about one and one-half times as great as that in hydrant water. The same dilution of sodium chlorid gave results somewhat less striking, but the elongation was well above the average of that in the hydrant-water checks.

As before stated, it would seem that instead of being injurious, dilute solutions of these salts might be decidedly advantageous, yet if they cause an unnatural growth their presence must be considered as detrimental rather than beneficial. Copeland calls attention to this fact, and is of the opinion that substances acting as stimulants are in the long run injurious.

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[a] Chemical Stimulation and the Evolution of Carbon Dioxide. Bot. Gaz., 35: 81–98 (1903).

It is of course an established fact that certain of these salts are beneficial and even necessary in particular cases. It has been claimed that chlorids are indispensable to buckwheat. The plant thrives well until it has passed the blooming stage, at a period when potassium chlorid seems necessary to complete the fruiting stage. This fact has apparently been demonstrated by experiment. Loew[a] says that fungi grown in culture solutions containing only traces of magnesia form no spores, but by increasing the amount of lethicin and thus adding more magnesium to the culture solution spores will be formed. Magnesium salts are as indispensable to fungi as to higher plants, but an exceedingly small amount is sufficient when the solution has an acid reaction.

Plants are often benefited by sodium salts.[b] While three of these salts—the chlorid, bicarbonate, and carbonate—are not indispensable to the plant, they accelerate ripening in some of the cereals.

Loew asserts that sodium, manganese, and silicon are often beneficial but not indispensable to phanerogams. Sodium salts are not essential in the physiological processes of plants, but are indispensable to animals.

PRACTICAL VALUE OF RESULTS.

There is certainly a very practical lesson to be drawn from the results described in this paper. It has of course long been known that plants of different genera and species show very different behavior when brought into relation with saline or alkaline soils. But the species itself may include a great number of different varieties or races, as in the case of wheat. It is not enough to know that wheat in general is better adapted to a certain region because of soil or climatic conditions than is Indian corn or cotton, but in addition it is necessary to know which of the many varieties of wheat is best suited to that region. Such knowledge might save many years of constant selection with a view to acclimatization.

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[a] The Physiological Rôle of Mineral Nutrients in Plants. Bul. 45, Bureau of Plant Industry, U. S. Dept. of Agriculture (1903).

[b] Chittenden and Wachsman are of the opinion that the conversion of starch into dextrin and sugar (diastase) is more vigorous in the presence of small quantities of sodium chlorid (0.24 per cent). Several investigators, prominent among whom are Sprengel and Liebig, have shown that various crops, and more especially beans, are much benefited by the application of small quantities of common salt.

Pethybredge (Bot. Centralbl., No. 33, 1901) is authority for the statement that the color of wheat leaves is intensified when sodium chlorid is applied.

S. Suzuki (Bul. Coll. Agric., Tokyo, 5: No. 2, p. 199) showed that potassium iodid, even in very high dilutions, exerted a stimulating action on the growth of the pea; and (ibid., No. 4, p. 473) that dilute quantities of potassium iodid stimulated oats. In opposition to these stimulating effects the same investigator has found (ibid., No. 4, p. 513) that vanadin sulphate, even in very dilute quantities, produced little or no stimulating action on barley, though he states that a very weak stimulating action on the roots seemed to have taken place in a 0.01 per mille of vanadin sulphate. He further shows (ibid., No. 2) that potassium ferrocyanid acts as a poison on plants in water cultures even in very high dilutions.

Soils are often known to contain sodium chlorid or magnesium sulphate or some other salt in such quantity as to be fatal to some varieties, while permitting others to flourish. Now, it has been possible by these experiments to determine that some varieties of wheat are much more resistant to a particular salt than others, and they are the ones which would be expected a priori to thrive best in a region where that salt predominates, other conditions being equal. By some of the experiments it was found that some varieties would thrive equally well in three times the concentration of sodium carbonate as others. A simple deduction from such results would be that for a region containing large quantities of "black alkali" the variety shown to have the greatest resisting power should be selected.

A knowedge of the limits of individual variation within each variety is likewise very essential. Often the most resistant varieties are not always the most desirable in other respects and a sort which is less resistant would be preferable. In case such a sort has a great individual variation in resistance to salts it should be comparatively easy to introduce it by gradual selection of the most resistant individuals, though a little more time would naturally be required than in introducing a variety that is already more resistant, as a smaller percentage of the plants would survive to furnish seed for the next crop.

It is believed, therefore, that the results of these experiments afford additional proof that the adaptation of useful cultivated plants to saline or alkaline soil conditions is one of the most promising of plant-breeding problems.

SUMMARY.

(1) The salts with which the experiments were made are injurious to wheat seedlings in the following order: Magnesium sulphate, magnesium chlorid, sodium carbonate, sodium bicarbonate, sodium sulphate, and sodium chlorid. This is asserted as true only of wheat, and a quite different order might possibly be established for other plants.

(2) The results obtained from a few individual seedlings are inaccurate and unreliable. A large number must be tested in order that

individual variation may be eliminated. Usually about ten days of experiment and from 60 to 100 seedlings were employed to establish the toxic limit for each variety in each salt.

(3) Wheat is one and a half to six times as resistant as white lupines, according to the salt used. In sodium bicarbonate the least and in magnesium sulphate and sodium carbonate the greatest difference in resistance between these two plants is shown.

(4) Different varieties, representing the two extremes, vary in the ratio of 1 to 3 in their resistance to the toxic effect of different salts. This is especially true for sodium carbonate and magnesium chlorid. In magnesium sulphate they vary in the ratio of 1 to 2.

(5) The variety most resistant as a whole is not necessarily the most resistant to every salt. The variety that averages least in resistance may be twice as resistant to some one particular salt as that which averages highest. In this fact may be found the secret of selecting a variety for a locality where the soil contains an excess of some one salt.

(6) The least resistant variety is not always the least resistant for every salt used. It may be exceedingly resistant to one or more salts and yet have a very low sum total resistance.

(7) It is not possible from the results with a few varieties to draw general conclusions for all sorts of wheat. Each will have to be worked out for itself.

(8) Varieties which come from localities where saline salts abound are the most resistant in water cultures to these toxic salts. Varieties from humid regions are less resistant.

(9) In general, the more toxic the salt the greater is the ratio of resistance of one variety to another. The less toxic the salt the smaller is the ratio. For sodium carbonate and magnesium chlorid the ratio of resistance is greatest, being as 1 to 3. For the remaining salts it is smaller.

(10) Individual variation is more prevalent and makes the establishment of the toxic limit much more difficult in some varieties than in others.

(11) All the salts used act as stimulants in dilute solutions except sodium carbonate and sodium chlorid, which were neutral even in very dilute solutions. In some cases the elongation in dilute solutions was nearly twice that occurring in the controls of hydrant water.

(12) Absolutely pure distilled water does not hinder development, but traces of zinc are sufficient to kill the root tips in twenty-four hours.

(13) The economic importance of these results is based upon the fact that water-culture experiments may be a means for saving several years of selection by indicating whether a certain variety is adapted to soil conditions in a particular region.

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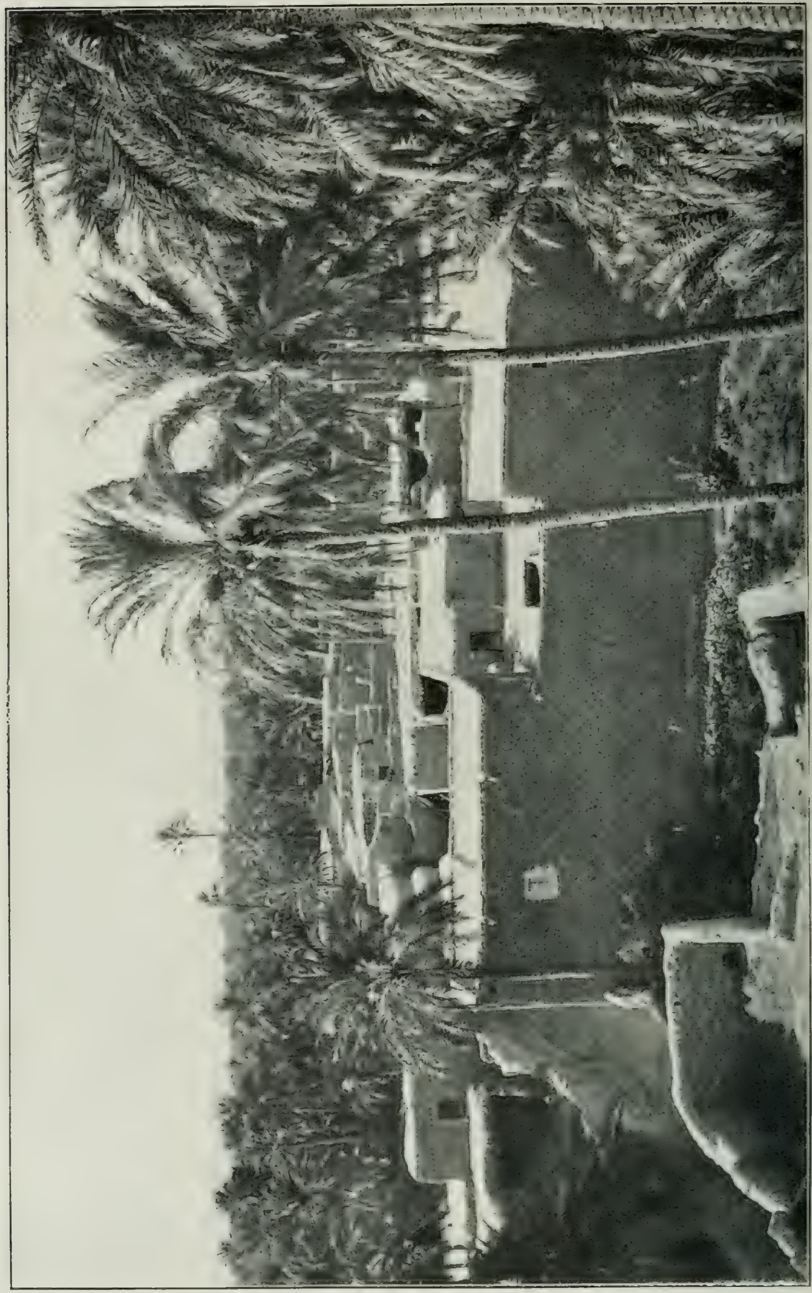
PLATE I.



OASIS OF BISKRA, ALGERIA, SHOWING DATE PALMS.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 80.

B. T. GALLOWAY, *Chief of Bureau.*

AGRICULTURAL EXPLORATIONS IN ALGERIA.

BY

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Physiologist, Vegetable Pathological and Physiological Investigations,
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AND

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SEED AND PLANT INTRODUCTION AND DISTRIBUTION.

ISSUED AUGUST 19, 1905.

239391
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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1905.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., April 24, 1905.

Sir: I have the honor to transmit herewith, and to recommend for publication as Bulletin No. 80 of the series of this Bureau, the accompanying manuscript entitled "Agricultural Explorations in Algeria."

This paper was prepared by Thomas H. Kearney, Physiologist, Vegetable Pathological and Physiological Investigations, Bureau of Plant Industry, and Thomas H. Means, at that time in charge of Soil Survey, Bureau of Soils, and has been submitted by the Botanist in Charge of Seed and Plant Introduction and Distribution, under whose direction the explorations described were conducted, with a view to its publication.

The four half-tone plates are necessary to a complete understanding of the text of this bulletin.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

While the agricultural explorers sent out by this Office are, as a rule, sent for the purpose of securing some special seeds or plants desired for introduction into the United States, they are also expected to make themselves as familiar as possible with the agricultural practices of the countries they visit and with the crops that succeed under the conditions described. That some of the practices observed may be profitably followed in those parts of the United States having similar soil and climatic conditions is more than probable, and that certain of these crops will prove useful has already been demonstrated.

The American farmer of to-day wants to know what is being done elsewhere, and he is especially interested in hearing how other people meet difficulties similar to those with which he has to contend. The reports of our agricultural explorers, we believe, will therefore fill a distinct place in agricultural literature. This report points out clearly the close similarity in climate existing between certain portions of the Southwestern States and Algeria, making it plain that we must look to that country for the introduction of many useful plants into our arid and semiarid districts.

We have, indeed, already availed ourselves of the opportunities thus offered. The date palms so far secured have come largely from Algeria; certain grains from that country, now being tested, give promise of unusual value; and the writers of this report brought back a quantity of alfalfa seed from salt-resistant plants, which has already been tested and gives promise of decided usefulness in Arizona and California.

To throw as much light as possible upon the conditions under which crops are grown in Algeria, chapters upon the topography, climate, irrigation, and soils are included. These, together with the brief historical and political sketch, have been prepared by Thomas H. Means. The remainder of the report was written by Thomas H. Kearney.

The writers wish to acknowledge the services cordially rendered them by the following-named gentlemen in the prosecution of their work: Mr. Henri Vignaud, of the United States embassy in Paris; the Governor-General of Algeria, and the French Resident at Tunis; Dr. L. Trabut, of the botanical service of the government of Algeria;

the Commandant of the Bureau des Affaires Indigènes at Algiers; the commandants of the military circles of Biskra and Tougourt; Lieutenant Beréaud, Chef du Bureau Arabe at the latter place; M. Colombo, of the Compagnie de l'Oued Rirh at Biskra; Mr. Daniel Kidder, United States consul at Algiers; M. Vilmorin, of the seed firm of Vilmorin-Andrieux & Co., and M. Emerich, agent of that firm for America.

A. J. Pieters,
Botanist in Charge.

Office of Seed and Plant
Introduction and Distribution,
Washington, D. C., February 17, 1905.

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AGRICULTURAL EXPLORATIONS IN ALGERIA.

INTRODUCTION.

The principal object of the writers' visit to Algeria was to secure for trial in the "alkali" lands of the western United States seed of such of the important field crops as might show indication of an unusual degree of resistance to salt in the soil. There was reason to believe that in northern Africa, if anywhere in the world, useful plants would be found to have developed such resistance through long cultivation in saline soils under a dry, hot climate.

Agriculture is too new in the arid part of America to make it likely that races in which the quality of resistance to "alkali" has become fixed should as yet have arisen there without direct efforts to breed them. But in the Sahara Desert, and in adjacent regions, all the conditions are favorable to the production of such races through natural selection. There we find the greatest continuous body of desert land in the world. The cultivated soils and the water used in irrigation often contain an excess of soluble salts. Finally, agriculture has been practiced there for thousands of years, and well-marked varieties of various cultivated plants have been developed.

As a matter of fact, it is already known to the Department of Agriculture that such salt-resistant races exist in northern Africa. Several of the agricultural explorers sent out by the Department have reported this to be true of Algerian wheats and barleys. Mr. W. T. Swingle brought back with him from the oases of the Sahara seed of alfalfa that was growing in soils containing a high percentage of salt. It was desirable, however, to determine just how resistant this Algerian alfalfa is and to obtain a larger quantity of the seed, in order that it could be fairly tested in the southwestern United States.

It is believed that this object was accomplished. The fact that alfalfa in the oases withstands a greater amount of soluble salts in the soil than ordinary American alfalfa was established beyond reasonable question. A sufficient quantity of seed was obtained to insure a thorough trial of it in parts of our country where a similar climate prevails. At the same time a careful search was made in various parts of Algeria for such other cultivated plants as might prove useful for salt soils. Incidentally the writers procured all possible information as to the character of the saline soils of Algeria, the way in which they are handled, and such attempts as have been made to reclaim them.

The coast region of Algeria strikingly resembles the corresponding part of California in climate, in physiography, and in the crops grown. The interior of California, and of the extreme southwestern United States generally, corresponds in many ways to the steppe and the desert regions of northern Africa. It is true that in some respects agriculture has reached a more advanced stage of development in California than in Algeria; yet there are probably some matters in which the French colony can give lessons to the American State. For this reason it seems advisable to present a sketch of Algerian agriculture as a whole, in addition to a more detailed account of the special subjects which the writers were sent out to investigate. The writers' stay in Algeria was limited to one month, from July 20 to August 20, 1902. It is fully realized that this length of time was entirely inadequate for anything like a thorough study of agriculture in the colony, especially as the mild winter permits crops to be grown at all seasons of the year. The date of the writers' visit to Algeria was determined partly by the necessity of reaching Egypt in time to study cotton at the height of its development, and partly by their desire to visit the oases of the Sahara at the season when the seed crop of alfalfa is being made. The information they could obtain by direct observation was necessarily fragmentary in the extreme. To supplement this, recourse has been had to the rather extensive literature of Algerian agriculture. In the preparation of this report the excellent work of Battandier and Trabut, entitled "L'Algérie" (Paris, 1898), has been freely consulted. Much information has also been drawn from papers upon special subjects by Doctor Trabut and others,[a] from the important "Manuel Pratique de l'Agriculteur Algérien" (Paris, 1900) of Rivière and Lecq, and from various other sources.

TOPOGRAPHY.

The French colony of Algeria is situated in northern Africa, between Morocco on the west and Tunis on the east. In general outline it is a rectangle, of which the greatest length—that from east to west—is about 650 miles. The area of Algeria is about 230,000 square miles, of which approximately 20,000,000 acres are under cultivation. The Mediterranean forms the northern boundary, while on the south the frontier extends well into the great desert of Sahara, the present outposts being from 300 to 500 miles from the coast.

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[a] Published chiefly in the "Bulletin Agricole de l'Algérie et de la Tunisie."

The vast desert to the southward cuts off Algeria physically as well as politically from tropical Africa. The influence of the sea upon its climate and the fact that almost unbroken overland communication with Europe by way of Morocco and Gibraltar has always been easy make Algeria rather an outpost of Europe than an integral part of Africa. In climate, physiography, flora, and agriculture Algeria is closely related to the countries that border the northern shore of the Mediterranean—Spain, southern France, and southern Italy. Indeed, geologists tell us that northern Africa was separated from southern Europe at only a comparatively recent period.

The part of the United States which Algeria most nearly resembles is California. The climate, agriculture, and state of development of the two countries are remarkably similar. In their general aspects they are much alike. In both, the coast region, being limited to a narrow strip by a range of mountains that parallels the seashore, has a comparatively mild, equable climate. In both countries this zone is preeminently adapted to fruit growing. Citrus fruits, olives, figs, and vines flourish there. A striking analogy exists between the great plain-like valleys of Algeria, occupied largely by vineyards and fields of cereals, and the San Joaquin and Sacramento valleys of California. Finally, the conditions obtaining in the Desert of Sahara are in great part reproduced in the Colorado and Mohave deserts. But to the steppe or high plateau region that occupies the central part of Algeria it would be more difficult to find a counterpart in California, portions of Nevada, Arizona, and New Mexico presenting a closer resemblance.

If we take into consideration biological—including agricultural—conditions, as well as the topographical features of the country, there are three principal regions into which Algeria can be divided for convenience of description. These are (1) the coast region, extending to the crests of the series of mountain ranges which follow the coast, (2) the high plateau or steppe region, occupying the central portion of the colony between the two great mountain systems and comprising the southern slope of the northern ranges and the northern slope of the southern chains, and (3) the desert region, comprising the Algerian Sahara and the southern slopes of the mountain system which forms the northern boundary of the Sahara.

The second and third regions are, on the whole, more homogeneous than the first, or, at any rate, their agricultural importance is too small to make it desirable to subdivide them. Three subdivisions of the coast region are, however, to be recognized, (1) the littoral zone, comprising the immediate coast and the lower slopes of the hills and mountains which border it, (2) the valley and plain zone, comprising the larger, often plain-like, valleys of the coast region which lie inside the line of hills that follows the seashore, and (3) the mountain zone, including the higher elevations of the coast region southward to the crest of the ranges that form the northern boundary of the high plateau region.

COAST REGION.

The "Tell," as the coast region is known among the Arabs, is, from an agricultural point of view, the most important part of Algeria. A great proportion of it is capable of cultivation. It has been estimated that a population of 12,000,000 could be supported in this region alone. It strikingly resembles the Mediterranean coast of Europe, and is no less close in its likeness to the coast region of California, so that a description of one will answer in many respects for both. The immediate seashore is bordered by hills and mountains, such as the Sahel of Algiers, the lower slopes of which are occupied largely by orchards and vineyards. In the higher elevations in the mountains agriculture is more difficult. Here there are extensive areas of grass land, grazed by flocks and herds, and important forests. Opening back from the coast and mainly parallel to it are a number of large valleys. Some of these, like the Mitidja, near Algiers, and the Chéliff, in the western part of the colony, are so extensive and so level of surface as to be practically plains with great areas of cereals and vineyards. The San Joaquin and Sacramento valleys in California are remarkably like these great valleys of Algeria. Smaller valleys, like the Mina and the Habra, where the bordering ranges of hills and mountains are not so far apart and there is less level surface, may be compared to the Santa Clara, Pajaro, and Salinas valleys in California.

These valleys and the lower slopes of the hills and mountains are the most highly cultivated part of the country, and support the densest population.

The more distinctively mountainous regions are naturally less adapted to agriculture; yet in the country known as Great Kabylia, the "Switzerland of Algeria," which contains the highest mountains of the colony, there is a very large population, the greater part of which is devoted to farming. This district lies to the east of Algiers. It forms an arc, of which the Djurdjura range of mountains is the chord and the seacoast is the circumference. For a long distance the crest of the Djurdjura range does not fall below 4,000 feet, while there are several peaks that exceed 7,000 feet in elevation. Lella Khedidja, the highest summit, has an altitude of 7,611 feet. Between this great chain and the coast there is a succession of high ridges separated by deep, narrow valleys and gorges. Anyone who has seen both regions will be struck by the resemblance between Great Kabylia and the Santa Lucia Mountains district of the western part of Monterey County, in California.

Numerous streams arise in the mountains of the coast region, traverse the Tell, and empty into the sea. Most of these are torrents, discharging large volumes of water in winter, but in summer dwindling to mere rivulets. Not infrequently no water is to be seen in the channel, but in that case it is generally to be found under the bed of the stream. Owing to their relatively great fall, and the denuded condition of much of the soil, the amount of erosion accomplished by Algerian water courses is disproportionately large. These characteristics are especially marked in western Algeria. In the eastern part of the colony, where the rainfall is better distributed and more of the surface of the country is forested, the flow of the streams is more regular. The small importance of Algerian water courses is doubtless to be accounted for by the fact that most of the precipitation occurs on or near the coast, while the interior of the country is extremely arid.

Only one river of the Tell region also traverses the high plateau region. That is the Chéliff, the most important water course in Algeria, which rises in the mountains that border the Sahara on the north. It has a total length of about 330 miles, draining an area of about 7,500,000 acres. Its flow in summer is only 100 to 175 cubic feet per second, although in winter from 500 to 2,000 cubic feet are discharged. It is obvious that only a small portion of the valley of the Chéliff can be irrigated throughout the year. Not even this stream is navigable, except, near its mouth, for small boats.

HIGH PLATEAU OR STEPPE REGION.

Between the two chief mountain systems of Algeria extends a vast region of elevated plains, with an average elevation of a little more than 3,000 feet above sea level. The greatest width of the high plateau in Oran Department is about 125 miles, whence it diminishes gradually toward the east until on the frontier of Tunis a narrow river valley is all that remains. In topography, and to some extent in vegetation, this region greatly resembles parts of Nevada and New Mexico. In its widest part it consists of a gently rolling expanse, sometimes without a hill to break the monotonous horizon. In other places isolated mountain groups rise like islands out of the sea. Near its northern and southern borders spurs from the mountain chains that bound it extend into the plain. Toward the east the mountains are higher and approach nearer together. In the Department of Constantine the distinctive character of the high plateau is lost, and it breaks up into a series of valleys a few miles wide, with gently sloping sides, separated by high hills and mountains. The great masses of the Aurès and

Babors groups, which border this part of the region, reach altitudes of 7,000 feet.

A marked feature of the steppe region is the frequently occurring "dayas" and "chotts"—salt ponds or lakes without outlet—which receive the drainage from the southern slopes of the coast mountains and the northern declivities of the Saharan range. They occupy basin-like depressions, and are often dry or merely marshy in summer, their beds being then covered with a shining crust of salt. The "bolson" plains of the Sonoran region in North America have a similar hydrography.

There is very little water in the high plateau region suitable for drinking or for the irrigation of crops. Occasional wells occur, and here and there are small pools where sheep and cattle drink. As a rule, however, travelers in this region must carry with them their supply of drinking water. Attempts to find artesian water have generally been unsuccessful.

In places the topography of the steppe region becomes almost identical with that of the desert—notably where areas of sand dunes occur and the vegetation is very scanty. Such localities differ from the desert proper only in their greater elevation and more severe winter climate.

DESERT REGION.

A considerable portion of the largest desert in the world, the Sahara, lies within the boundaries of Algeria. Contrary to the general notion, the mean elevation of this desert above sea level is considerable, being placed by some authorities as high as 1,540 feet. Broadly speaking, the surface of the desert is convex, the central portion being generally higher than the borders. The desert is commonly pictured as a vast billowy expanse of sand blown about by the sirocco and dotted with oases. This conception is only partly true. As a matter of fact, the topography of the Sahara is as diversified as that of most areas of equal extent in other parts of the world. In this respect it is to be compared with the desert regions of the southwestern part of the United States. The Sahara contains mountains nearly 7,000 feet high, upon whose summits snow remains throughout the winter. Other parts are considerably below sea level. Much of its surface is broken by ranges of sand dunes and of rocky hills, between which lie narrow ravines or wide valleys. In other quarters extensive plateaus occur. The courses of streams that must once have carried a considerable volume of water can be traced in many places. The infrequent rains that fall in the Sahara sometimes fill the bottoms of these channels with water for a few brief hours. But even such transient torrents can effect a tremendous amount of erosion in the loose soils of the desert, there being little vegetation to hold them in place. Lakes and ponds are numerous in the lower portion. Here and there, but forming only a small fraction of the entire area, are oases, watered by springs and wells, where groves of date palms flourish.

Schirmer[a] gives a graphic description of the Sahara. He writes:

> The desert, more than any other part of the surface of the globe, has the appearance of immobility. The implacable climate has depopulated the land. The great plains have an aspect of absolute emptiness. The mountains are like skeletons from which the sun has devoured the flesh. The dunes look like solidified waves of dull gold. The absence of sound is such that, as one traveler has put it, "One hears the silence." Everything appears unchangeably fixed in the intense light.

Pomel estimates that only about one-ninth of the total area of the Sahara is covered with sand dunes. The higher dunes occur in more or less regular chains, which have often been likened to the waves of the sea, caught and petrified. These sand hills sometimes reach a height of 1,000 feet. Smaller dunes, very regular in their rounded outline, often cover extensive areas, as, for example, between Biskra and the Melrirh Chott. Dunes of this character are generally formed by various desert shrubs and herbs that are able to send up new shoots through the sand which drifts over them from time to time, thus continually raising the height of the dune. The largest sand hills are often formed about rocks and cliffs, which arrest the drifting sand. The soil of the dunes is a fine and remarkably homogeneous sand.

Contrary to the general notion, the larger dunes are not continually shifting their position, but are sufficiently permanent features of the landscape to have received in many cases names that are handed down by the Arabs from generation to generation. For this reason, and because drinkable water and vegetation are more apt to occur near the dunes than elsewhere, the caravan routes in the Sahara follow the dunes wherever possible.

In western Algeria the desert is high. Hills and mountains of sunscorched rock, with smooth surfaces and sharp, unworn edges, rise out of stony plains. Jagged cliffs, often of the most fantastic form, stand sentinel over the deep canyons and gorges that have been cut out by occasional torrents. Oases are few and far between. This is, indeed, the most barren and inhospitable part of the desert.

Toward the east the altitude of the desert decreases until, near the frontier of Tunis, a region of chotts, or salt lakes, lying below sea level, is reached. During most of the year the bottoms of these basins are dry or, at most, muddy beneath a crust of glittering white salt, which gives rise to remarkable displays of mirage. But during the winter they are partly filled by streams that descend from the mountains on the west and north. The eastern part of the Sahara in Algeria is mainly flat or gently rolling. Its surface is covered with sand.

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[a] Schirmer, Le Sahara, p. 139 (1893).

often collected into dunes of greater or less size (erg). There are also extensive areas where the nearly plane surface is composed of smooth rock or hardened alluvial clay (hamada).

A great valley, some 60 miles long and about 12 miles wide, known as the "Oued Rirh," forms the most valuable portion of the Sahara of Algeria. It is really the bed of an extinct river. It is largely below or only slightly above sea level, the maximum depression—the extensive salt lake known as "Chott Melrirh"—being 107 feet below sea level. Subterranean streams of considerable volume underlie the surface in this region. These are doubtless fed by water which flows down from the mountains and sinks through the desert sands until it meets an impermeable layer of clay or of rock, over which it flows. The Oued Rirh Valley has been described as a "small Egypt with a subterranean Nile." By means of wells this water has been utilized in the creation of oases, where hundreds of thousands of date palms flourish.

The idea, once generally held, that the entire Sahara is the bed of an ancient sea has been abandoned. Only for the part known as the Oued Rirh, a small fraction of the whole desert, is this theory still entertained by some authorities. Here there is a series of large salt lakes, some of them below the level of the sea, which extends across Tunis almost to the Gulf of Gabès.

CLIMATE.

The greater part of Algeria has a warm, temperate climate, very similar to that of California. The climates of both countries are determined in large measure by the combined influence of three factors—the ocean, the mountains, and the desert. In Algeria, as in California, most of the rainfall occurs during the mild winter, while the long summer is almost perfectly dry. Furthermore, the direction of the prevailing winds at different seasons is in both countries largely effective in regulating conditions of temperature and of rainfall. The lower part of the coast region has a wet and a dry rather than a warm and a cold season. The higher mountains, however, and the high plateau are characterized by a decidedly cold winter. Algeria would be wholly a desert were it not for the northwest winds, charged with humidity, which blow from the sea, especially during the winter and spring. Their influence is, of course, most marked in the coast region, which has, in consequence, the heaviest rainfall, the most humid atmosphere, and the most luxuriant vegetation of any of the three zones.

The mountain chains which follow the coast line intercept a large part of the moisture carried by the sea winds, so that, while their northern, seaward slope has a comparatively heavy rainfall, their southern slopes and the high plateau region beyond are quite arid. What moisture passes across the mountains of the first system is largely withdrawn from the atmosphere when it reaches the second, which bounds the steppe region on the south. Consequently, the desert beyond receives an insignificant share of atmospheric moisture from the Mediterranean.

Winds that come from the opposite direction—out of the Great Sahara—are, of course, at all seasons extremely dry. It is in late summer—especially in September—that the dreaded sirocco, the hot, sand-laden wind of the desert, is strongest and most frequent. Then it blows for days at a time over the high plateau and the two mountain ranges that form its boundaries, into the Tell, and even across the Mediterranean into southern Europe.

The three principal physiographical regions coincide with the most important climatic regions of the colony. For a further examination of this subject it will therefore be advisable to take up each in its turn, beginning with the coast region, or Tell.

In the tables given below, climatic data from Algerian localities are copied from Thevenet's "Essai de Climatologie Algérienne." For comparison, data from various places in the western United States where similar conditions obtain are also included. These are taken from publications of the United States Weather Bureau. Much information regarding the climate of Algeria has also been drawn from the excellent little work of Battandier and Trabut, previously mentioned. Owing to the paucity of accurate records and the small agricultural importance of the high plateau region, no tables are given for that part of the colony. It should be remarked, however, that Sétif, which has an elevation of 3,560 feet, although here included in the tables for the coast region, is sometimes considered as belonging to the high plateau, and the climatic data from this point are doubtless fairly applicable to the uncharacteristic eastern portion of that region. Again, Bou Saada, figures from which locality are given in the tables of climate of the desert region, really belongs to the extremely desert-like portion of the high plateau.

COAST REGION.

TEMPERATURE.

The littoral zone of the coast region has a mild winter, resembling that of the California coast. Temperatures at noon of 70 to 75 F. for fifteen days or a month at a time are not of rare occurrence in winter. The temperature never descends much below freezing, and does not remain at that point for any length of time. Still, temperatures of 23 F., such as are sometimes recorded by thermometers placed 4 inches above the surface of the ground, can do considerable damage to the winter crops of garden vegetables, although the soil itself is never frozen to any considerable depth. The cold often seems more intense than is actually the case, because of the humidity of the atmosphere and the lack of facilities for heating the houses. A temperature of 45° F. is considered very disagreeable. A few miles back from the shore line, behind the first range of hills, for example, in the Mitidja plain, near Algiers, light frosts are frequent and have been known to occur as late as May. Snow, which has never remained on the ground for an entire day at Algiers, has lain for three days to a depth of 7.5 inches in the country only a few miles back from the coast.

In summer, except during the sirocco, the shade temperature of the littoral zone rarely exceeds 86° F., but sometimes rises to 105° F. when the wind from the desert is blowing. At such times the nights are often as hot as the days. The moderate summer temperatures are largely due to the sea breeze, which rises every morning at about 10 o'clock. As far inland as the influence of this wind is felt comparatively mild summer temperatures prevail.

The climate of the littoral zone is much like that of the coast of southern Europe; but fall-sown crops mature even earlier than there, by reason of the milder winter and the higher temperatures in spring. Hay is harvested in May and cereals in June in this zone.

The valley and plain zone of the coast region has a more extreme climate than the littoral zone. This difference has already been indicated in comparing the Mitidja Valley with Algiers, on the neighboring coast. The great Chéliff Valley, farther west, presents a still more marked contrast. Here, owing to the greater dryness of the atmosphere, frosts are more frequent and more severe in winter and spring than along the coast. On the other hand, in summer the hills which bound these valleys on the north shut off the sea breeze, and the heat is consequently more intense. Sunstroke and prostration from heat are by no means unknown in the Chéliff Valley. The sirocco, also, is more severely felt than in the littoral zone, which is partly protected against this south wind by the rampart of hills that rises a short distance back from the shore. More elevated places, like Sétif, have even severer winters, resembling those of the high plateau region. Sharp frosts are frequent as late as April and May. The summer temperatures are often very high in the daytime, but the air is fresher than in the valleys and the nights are nearly always cool.

The mountain zone of the coast region is not dissimilar in climate to mountainous regions of southern Europe. The winter, especially at the higher altitudes, is much more severe than in the littoral zone. On the crest of the Djurdjura range, at 7,000 feet elevation, snow often reaches a depth of 3½ feet and remains on the ground until the latter part of July. The summer temperatures are almost invariably moderate in the mountain region, except when the sirocco is blowing.

The smaller relative humidity also contributes toward making the summer climate an agreeable one. Springs with a mean annual temperature of 45° or 50° F. are not infrequent at high elevations in the Djurdjura range.

TABLE 1.—*Mean temperatures (in degrees Fahrenheit) of localities in the coast region of Algeria, as compared with the California coast.*

Month.	Algeria.					California.					
	Oran.	Orléansville.	Algiers.	Fort National.	Sétif.	Los Angeles.	San Luis Obispo.	San Francisco.	Fresno.	Sacramento.	Colfax.
January	50.9	45.8	54.0	41.2	39.0	53.0	51.2	50.1	45.2	45.2	44.3
February	51.8	47.7	54.0	42.2	40.4	54.4	55.3	52.2	51.5	49.6	45.8
March	55.4	53.1	56.5	46.8	46.0	56.4	52.2	53.6	54.0	54.3	49.1
April	59.2	55.8	59.5	50.2	49.8	60.0	56.0	55.0	60.9	59.0	54.2
May	64.0	63.5	64.6	55.9	56.7	62.0	57.6	57.0	67.3	64.5	61.7
June	69.4	71.6	70.0	66.6	66.7	65.9	62.9	59.0	74.6	70.0	71.4
July	74.1	80.1	75.4	74.7	74.8	70.8	66.2	58.8	82.1	73.6	75.1
August	75.4	79.7	76.1	75.4	73.4	72.0	65.0	59.3	81.4	70.6	77.0
September	71.1	72.3	72.9	67.3	65.5	68.5	65.4	60.9	74.2	70.0	69.7
October	63.7	61.0	65.8	56.1	53.6	64.0	62.0	59.9	63.4	60.0	59.8
November	57.2	53.2	60.4	48.9	45.2	60.0	57.8	56.4	54.7	53.4	51.4
December	51.6	46.8	54.0	42.2	39.6	56.4	52.6	51.6	46.3	47.2	46.3
Year	62.0	60.9	63.6	55.6	54.2	62.0	58.7	56.2	63.0	59.7	58.8

A comparison of the temperatures of localities in Algeria and in California, as given in Table 1, is instructive. Of the Algerian stations, Oran and Algiers are situated on the seaboard, the first in western, the second in central Algeria. Data from these localities should be representative of conditions along the coast, except in the extreme eastern part of the colony. With them are to be compared San Francisco, San Luis Obispo, and Los Angeles, representing the coast of California. Orléansville is the metropolis of the great valley, or rather plain, of the Chéliff, the most important of the large inland valleys of the coast region in Algeria. Sétif, as has already been remarked, lies south of the mountain chain that bounds the coast region, and has an elevation of over 3,000 feet. Topographically, and in some of its climatic peculiarities, it belongs rather to the high plateau than to the coast region, although agriculturally it is more nearly related to the latter. Fresno and Sacramento are representative points in the two great interior valleys of California—the San Joaquin and the Sacramento. They should afford an interesting comparison, especially with Orléansville. Fort National, at an elevation of over 3,000 feet, in the heart of the most mountainous region of Algeria, is to be compared with Colfax, in the foothills of the Sierra Nevada, north of the center of California.

Oran has the same mean yearly temperature as Los Angeles, but has higher mean temperatures for the summer and lower for the winter months, so that Los Angeles has the more equable climate. At Algiers the yearly mean temperature is not very different from that at Oran, but the mean temperatures for the winter months are generally higher. San Francisco and San Luis Obispo fall considerably below the Algerian coast towns in yearly mean temperature. The mean temperatures for the summer months also are decidedly lower at the California localities. The mean temperatures in winter correspond more closely.

Orléansville shows a remarkable resemblance in distribution of temperatures to the similarly situated town of Fresno, in California, and in this repect somewhat less to Sacramento. In yearly mean temperature, however, Orléansville is nearer Sacramento. Sétif, as would be expected, differs considerably from Orléansville, Fresno, and Sacramento in yearly and monthly means of temperature. Its resemblance to the high plateau is expressed in the fact that the nights are always cool in summer and the winter temperatures are low, falling at times to 12° F. The mountain stations, Fort National and Colfax, show a close approximation in monthly and yearly mean temperatures.

HUMIDITY.

The relative atmospheric humidity in the littoral zone is fairly uniform throughout the year. Owing to the proximity of the sea it is at all seasons considerable, the average for the year being 73 per cent. This condition of humidity is interrupted only when, generally in late summer and in early autumn, the sirocco blows for a day or more at a time. The humidity is far greater in the eastern than in the western part of the colony. The large percentage of moisture in the atmosphere causes the discomfort from cold in winter, and from heat in summer, to be out of all proportion to the actual temperature.

The dry season, so far as the littoral zone is concerned, owes its character to the lack of actual precipitation rather than to the absence of humidity in the air. Night fogs are frequent when east or northeast winds are blowing, and in August it is often 9 o'clock in the morning before they disappear. Dew is also copious at this season.

Atmospheric humidity, like precipitation, decreases as one goes farther from the coast. It is already perceptibly less in the mountains and in the great valleys of the coast region than along the seaboard.

PRECIPITATION.

In Algeria precipitation is almost synonymous with rainfall, except in the higher mountains, for elsewhere the amount of precipitation in the form of snow is unimportant. Hailstorms are fairly frequent, occurring, on an average, seven times a year. Market gardens of the littoral zone sometimes suffer severely from spring hailstorms, and, in exceptional localities, vineyards and orchards are occasionally damaged. Hail is more important for this reason than as contributing much to the total precipitation.

In the coast region of Algeria, as in many warm temperate and tropical countries, the distribution of the rainfall is more important than that of heat in determining the characteristics of the principal seasons of the year. Its distribution is largely controlled by the direction of the prevailing winds. In winter strong northwest winds, blowing from the Mediterranean, are of frequent occurrence and bring most of the rainstorms. They begin in the autumn, sometimes as early as the first of September, and usually cease in May or June. Even in midwinter, however, a clear sky for fifteen or thirty days at a time is not a rare event. During the summer there is a light sea breeze during the day, but winds of greater violence come almost wholly from the south, and are dry and hot.

More rain falls annually on the coast of Algeria, especially on the eastern coast between Algiers and Tunis, than in a great part of Europe. Notwithstanding this, Algeria has a decidedly more arid summer than any part of Europe, except, perhaps, extreme southern Italy and portions of Spain. This is due to the unequal distribution of the rain among the different seasons.

In the littoral zone winter is a wet rather than a cold season. It is then that most of the native vegetation, as well as crops that are not irrigated, must make their growth. The dry season is a period of rest for soils that are not artificially watered. Light showers of brief duration, such as occasionally fall during the summer, are of small importance in their effect upon the climate and vegetation. In the large inland valleys of the coast region the summer drought is still more pronounced than on the coast.

In the mountain zone, particularly at the higher elevations, rain is more evenly distributed, and the seasons are more like those of middle Europe. The rainfall in March and April is particularly heavy. In Great Kabylia thunderstorms and hail, which in the littoral zone occur only in winter, are not infrequent throughout the summer. This, with the partial protection from the sirocco afforded by the higher ranges, makes the summer drought less pronounced than in the littoral zone and in the valley and plain zone. But the total amount of precipitation in summer is, after all, comparatively insignificant. Even in the mountains, summer retains its characteristics as the dry season of the year. In winter the rainfall is quite considerable. The northern slopes of the Djurdjura range receive the heaviest precipitation occurring in the country—over 40 inches a year. These high mountains form a barrier which intercepts most of the cloud laden winds from the sea, so that the country immediately to the south of them is extremely arid.

Rainfall is very unevenly distributed in different parts of the coast region and even of the littoral zone proper. One reason for this is the great difference in latitude—about two degrees—between the easternmost and the westernmost point of the Algerian coast. While the total annual precipitation on the coast near the Tunisian border amounts to nearly 40 inches, on the frontier of Morocco it is less than 16 inches. From year to year, also, the total amount and the distribution vary enormously.

TABLE 2.—*Rainfall (in inches) of localities in the coast region of Algeria, as compared with the California coast.*

Month.	Algeria.					California.					
	Oran.	Orléansville.	Algiers.	Fort National.	Sétif.	Los Angeles.	San Luis Obispo.	San Francisco.	Fresno.	Sacramento.	Colfax.
January	3.05	1.73	4.35	5.58	1.62	2.93	5.69	4.92	1.53	3.82	8.81
February	2.64	1.85	3.68	3.49	1.68	3.27	1.55	3.49	1.33	2.80	6.89
March	2.42	2.28	3.42	6.24	2.34	2.98	3.46	3.22	1.74	2.86	6.78
April	1.67	2.15	2.36	5.20	2.05	1.36	.93	1.84	1.11	2.13	4.48
May	1.42	1.38	1.40	2.99	1.82	.43	.35	.73	.50	1.01	2.36
June	.29	.55	.57	1.13	1.08	.10	.19	.14	.18	.17	.62
July	.07	.06	.06	.22	.28	.02	.01	.02	Trace.	.02	.03
August	.08	.08	.28	.28	.79	.03	.03	.02	.01	.01	.01
September	.65	.76	1.12	1.75	1.17	.08	.36	.22	.26	.32	.53
October	1.61	1.78	3.11	4.51	1.44	.74	1.62	1.02	.67	1.11	1.95
November	2.38	2.29	4.37	4.99	1.52	1.38	1.16	2.72	1.15	2.20	4.40
December	2.90	2.48	5.49	7.30	2.05	3.98	3.08	4.99	1.78	3.69	8.70
Year	19.18	17.39	30.21	43.68	17.84	17.30	18.43	33.33	10.27	20.14	45.56

When we compare Algeria with California as to rainfall, we find that the annual total precipitation at the two coast towns, Oran and San Luis Obispo, is very nearly the same. At Los Angeles it is somewhat less. January is the month of greatest rainfall at Oran and San Luis Obispo, February at Los Angeles. July is the month when the least rain falls at all three points. The precipitation is much heavier, and nearly the same in total amount at Algiers and at San Francisco. There is also considerable similarity in the distribution during the year of the rainfall at these two places.

The rainfall at Orléansville greatly exceeds that at Fresno, but is somewhat less than that at Sacramento. Sétif agrees closely with Orléansville in yearly total and in distribution of the precipitation. As for the mountainous districts of the two countries, as represented by Fort National and Colfax, there is a very close correspondence in yearly totals, but in respect to distribution the resemblance is less striking. The rainfall in summer at Fort National is greater and that in winter less than at Colfax.

WIND.

Winds from every point of the compass occur at different seasons in the coast region. As has already been mentioned, the characteristic winter wind is from the northwest, off the Mediterranean. This often rises to the height of a gale, and is of sufficient importance to decide the direction in which trees along the seashore are bent. West winds are also common in winter. In summer, the most violent wind is the occasional sirocco, from the Desert of Sahara, an extremely hot, dry wind, which sometimes blows day and night for several days at a time, filling the air with the fine dust it carries. It often does great harm to crops, vineyards and ripening grain being particularly liable to injury. The sirocco also blows in winter, but its violence is less at that season and it is cooler and moister. The regular summer wind is, however, the sea breeze from the northeast, which springs up every morning and is of great importance in moderating the temperature. East winds are also frequent in summer. At night, on the other hand, the prevailing wind is from the south. Absolute calm is not infrequent. In proportion as we travel farther from the coast, the effect of winds from the sea becomes less perceptible and that of the desert winds more pronounced. This difference becomes strongly marked after the northern mountain system is crossed.

The sirocco is the most striking climatic feature in which Algeria differs from California. In southern California a wind from the desert, known as the "Santa Ana" wind, blows occasionally, but in duration and severity it is not to be compared with the Algerian sirocco.

HIGH PLATEAU REGION.

The small agricultural importance of the high plateau region makes it unnecessary to discuss its climate at any great length. Owing to its greater elevation and distance from the sea, conditions are more extreme than in the coast region. The winters are colder and the summers hotter. Winter temperatures as low as 7° F. have been known, while in summer a temperature of 105° F. is often experienced. Daily variations amounting to 85 degrees have been recorded. In its severe winters the high plateau region resembles the highest altitudes of the mountain zone of the coast region, but differs in its hotter temperatures in the daytime in summer. In the latter respect it resembles the desert region, but there the nights are warmer in summer and the winter is much milder. Battandier and Trabut[a] mention one point in the high plateau region, at an elevation of about 4,700 feet, where the mean temperature for ten years was about 44.5° F. in winter, 55.5° F. in spring, 79° F. in summer, and 62° F. in autumn. The yearly mean temperature was 62° F.

The rainfall is much less than in the coast region, but no exact data on this point are available. Rain falls usually in sudden and violent showers. Storms are more frequent during the summer than is the case along the coast. The amount of precipitation is trivial, although sometimes sufficient to moisten the ground. During the winter the soil, especially in depressions, contains enough water in occasional years to bring a crop of barley without irrigation. The atmospheric humidity is almost always very small.

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[a] L'Algérie, p. 118.

DESERT REGION.

TEMPERATURE.

If we had no other data concerning the climate of the Sahara than the mean annual temperature, we should suppose it to be a very mild one. The variations from the yearly, monthly, and daily means are, however, enormous. Winter temperatures of 18° F. and summer temperatures of 112° F. are by no means uncommon. The daily range sometimes exceeds 86 degrees. The unshaded soil—sandy or rocky—becomes heated up to 160° F. At Biskra, which is by no means extreme in its summer climate, it is said to be possible sometimes to cook an egg in the sand. In the Oued Rirh region, on the other hand, ice sometimes forms in winter in the irrigation ditches. Evaporation is undoubtedly very great, but no accurate records of this phenomenon have been kept in the Sahara.

TABLE 3.—*Mean temperatures (in degrees Fahrenheit) of localities in the desert region of Algeria, as compared with similar localities in the southwestern United States.*

Month.	Algeria.				United States.			
	Tougourt.	Biskra.	Quargla.	Bou Saada.	Yuma, Ariz.	Phoenix, Ariz.	Tucson, Ariz.	Volcano Springs, Cal.
January	47.3	50.5	46.8	44.4	54.1	49.8	49.6	55.9
February	49.8	53.2	51.8	45.8	58.6	54.3	53.6	60.5
March	54.9	58.3	59.9	51.1	63.9	53.9	59.4	68.4
April	64.0	63.1	66.4	56.8	69.9	67.0	65.6	79.7
May	74.8	71.8	73.6	65.1	76.9	74.4	74.5	87.5
June	86.0	80.6	82.4	75.0	84.4	83.9	84.0	96.6
July	92.1	87.1	90.7	83.1	91.2	90.2	87.7	101.3
August	85.1	85.8	86.0	82.8	90.4	88.2	85.9	99.7
September	83.7	78.8	78.1	73.0	84.3	81.4	80.8	89.5
October	68.4	67.6	63.5	60.3	72.4	69.3	70.4	78.4
November	58.5	57.2	52.9	50.0	62.3	58.5	58.5	67.0
December	48.9	51.3	45.0	44.0	55.9	52.3	51.6	57.4
Year	67.8	67.1	66.4	60.9	72.0	68.6	68.5	78.5

Of the stations in the Algerian desert comprised in the accompanying table of temperatures, Bou Saada, at an elevation of 2,194 feet, belongs rather to the high plateau region, lying north of the mountain chain which forms the boundary of the Sahara. It is in a region, however, where the conditions are entirely desert-like, closely resembling those of the higher western part of the Sahara. The other three stations are in the low eastern part of the Sahara proper. Biskra can hardly be regarded as a typical locality, being just within the limits of the desert, only a few miles south of the mountains which form the northern boundary of the Sahara. Biskra is 407 feet above sea level. Tougourt, 120 miles farther south, in the Oued Rirh country, is the center of some 40 oases, where hundreds of thousands of date palms are grown. Its altitude above mean sea level is 226 feet. Ouargla, well into the Sahara, 120 miles still farther south, has the same elevation.

Among the localities in the extreme southwestern United States selected for comparison, Tucson, Ariz., with an elevation of 2,387 feet, resembles in situation Bou Saada. Phoenix (altitude, 1,100 feet) may be compared with Biskra. At Yuma (altitude, 137 feet), and still more at Volcano Springs (228 feet above sea level), conditions would be expected to resemble in many respects those prevailing at Tougourt and at Ouargla. A comparison of the figures in these tables shows that the Colorado Desert in southern California is warmer than the Sahara in Algeria. Volcano Springs has an annual mean temperature 10.7° F. higher than Tougourt, and in summer the maxima are higher. The extreme minimum temperatures in Arizona and California are lower than those in the Sahara. For example, the lowest recorded temperature at Biskra is 29.7° F., while at Phoenix, Ariz., the minimum frequently falls to 25° F., and has been as low as 12° F.[a]

HUMIDITY.

While the actual amount of water vapor in the air is sometimes quite appreciable in the Sahara, the relative humidity is always low, because of the high temperatures. In summer the average relative humidity is only 28 per cent, and for this reason the excessive heat is less uncomfortable than would otherwise be the case. So extreme is the dryness of the atmosphere that one's skin is seldom wet with perspiration, even on the hottest days. Dew is rarely precipitated, and although freezing temperatures are by no means unknown in winter, white frost is not common. The sky over the Sahara is generally cloudless and very clear, particularly in the night time.

TABLE 4.—*Mean relative humidity (in percentages) of localities in the desert region of Algeria, as compared with Yuma, Ariz.*

Month.	Algeria.			United States.
	Biskra.	Ouargla.	Bou Saada.	Yuma.
January	61.6	60.1	65.5	45.4
February	55.3	67.5	60.7	43.8
March	52.0	55.0	50.7	43.0
April	48.2	47.0	46.9	35.1
May	42.9	37.3	42.0	36.7
June	36.4	35.6	34.1	34.7
July	32.6	29.4	25.4	42.8
August	35.6	25.3	26.4	47.7
September	44.1	28.6	39.1	44.7
October	51.2	52.0	47.6	46.2
November	58.5	62.1	57.8	43.3
December	62.5	66.4	64.8	51.4
Year	48.4	47.2	46.8	42.9

The three stations in the Algerian Sahara where records of relative atmospheric humidity have been kept all show an annual mean higher than that of Yuma, the only locality in the desert region of the southwestern United States where accurate records have been kept. But, while in winter the humidity is greater in the Algerian Sahara than in southwestern Arizona, in summer the reverse is true.

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[a] For a detailed comparison of the climate of the Algerian Sahara with that of the extreme Southwestern States, see Bulletin No. 53 of the Bureau of Plant Industry, U. S. Department of Agriculture, The Date Palm and Its Utilization in the Southwestern States, by Walter T. Swingle, 1904, pp. 52–70.

PRECIPITATION.

A widely received explanation of the peculiar conditions of the Sahara, as regards atmospheric water, is as follows: The central portion of the desert is sufficiently elevated to be considerably colder in winter than the Atlantic Ocean to the west and the Mediterranean Sea northward. Consequently, the general direction of winds in winter is from the center toward the edge of the desert, which precludes the possibility of much rainfall at that season. In summer, on the other hand, the normal winds blow toward the highly heated center of the desert, although there are occasional siroccos in the contrary direction. These normal summer winds from the Atlantic and Mediterranean would cause rainfall in summer were it not that physiographical conditions intervene to prevent this. Winds from the west encounter a cold current that follows the Atlantic coast of northern Africa, and the greater part of the moisture they carry is condensed before they reach the mainland. The high summits of the coastal mountain system of Algeria intercept and condense most of the water vapor that is brought in by winds from the Mediterranean. What little moisture escapes this barrier and crosses the high plateau is mostly given up when the mountains along the northern border of the Sahara are encountered. Furthermore, in the desert itself there are few mountains of sufficient elevation to condense what water vapor passes the second barrier.

Notwithstanding these conditions, rain is by no means unknown in the Sahara. Heavy precipitation sometimes occurs, but its distribution is very irregular, both in point of time and of place. Localities in the desert are known which have received no appreciable amount of rain for ten years or more. At other times a cyclone may cause a sudden heavy downpour. Violent torrents are formed and a great amount of erosion is accomplished in a few hours. The higher elevations of the isolated mountain masses of the Sahara have a somewhat more regular rainfall, but it is believed that, on the whole, evaporation exceeds precipitation in the Sahara, and that its aridity is steadily, although imperceptibly, increasing.

TABLE 5.—*Rainfall (in inches) of localities in the desert region of Algeria, as compared with similar localities of the southwestern United States.*

Month.	Algeria.				United States.			
	Tougourt.	Biskra.	Ouargla.	Bou Saada.	Yuma, Ariz.	Phoenix, Ariz.	Tucson, Ariz.	Volcano Springs, Cal.
January	0.61	0.67	0.50	0.79	0.48	0.80	0.79	0.25
February	.54	.68	.30	.79	.41	.70	.90	.39
March	.80	.69	.88	1.32	.27	.58	.77	.07
April	.44	.83	.36	1.56	.08	.30	.27	Trace.
May	.39	.72	.13	1.55	.03	.13	.14	Trace.
June	.04	.31	.11	.67	.00	.10	.26	.00
July	.03	.12	.00	.32	.13	1.03	2.40	.12
August	.02	.14	.00	.31	.33	.88	2.60	.09
September	.31	.80	.00	.91	.15	.64	1.16	.00
October	.43	.59	.22	.87	.23	.37	.64	.12
November	.54	.42	.50	.64	.26	.54	.81	.07
December	.88	.74	.61	.88	.46	.86	1.00	.52
Year	5.01	6.73	3.61	10.61	2.83	6.93	11.74	1.64

A comparison of precipitation in the Algerian desert and that of the southwestern United States is instructive and interesting. Bou Saada has approximately the same annual total as Tucson, which it resembles in situation and elevation, but there is the same difference in distribution as was noted in the case of atmospheric humidity. More rain falls in winter and less in summer at the Algerian than at the Arizona locality. At Biskra and Phoenix very nearly the same total amount of rain falls during the year, and the distribution at the two points corresponds more closely than as between Bou Saada and Tucson. At Ouargla and at Tougourt the rainfall is considerably greater in yearly total than at Yuma and at Volcano Springs. In distribution, however, these four stations resemble each other to a considerable degree. On the whole, if we consider only localities which represent the most extreme conditions in both great arid regions, it would appear that the desert country of the southwestern United States is decidedly drier than the Sahara of Algeria.

IRRIGATION.

Algeria is less fortunately endowed than Egypt as regards water supply. She has no large river like the Nile, containing even at its lowest stage a very considerable volume of water for irrigating purposes. On the contrary, the water courses of the French colony are of a torrential character, running high after heavy rains but dwindling to mere rivulets in summer. Most of them are short, rising in the mountain ranges of the coast region, and thus not draining a sufficiently large area to gather a great volume of water. Their fall is heavy, and they accomplish a vast amount of erosion, so that when high their waters carry a large amount of silt. Even the Chéliff, which has its source in the mountains that form the northern boundary of the Sahara and traverses the entire width of the high plateau, is but an insignificant stream in summer. Rainfall is too scanty, even at a short distance from the coast, to feed large rivers. For this reason irrigation in Algeria must necessarily be on a more modest scale than in Egypt. As a matter of fact, the area under irrigation at present is only a small fraction of the total area of the colony.

The littoral zone of the coast region, particularly in the eastern part of the colony, receives quite enough precipitation in winter for the growing of most crops. In summer, however, there are very few parts of Algeria where field crops can be grown without irrigation, at least without a radical change in the methods of cultivation generally followed in the colony. Orchards and vineyards, however, can be made to pay in some places without artificial watering. This is notably the case in the mountain zone, where steep slopes, ill adapted to irrigation, are covered with fruit trees. In the valley and plain zone of the coast region irrigation is almost indispensable in summer, and even the winter cereal and forage crops are greatly benefited by an occasional watering. In the high plateau region nothing can be grown in summer without irrigation, and in winter it is only in an occasional depression that the natural moisture is sufficient to bring a crop. In the desert region artificial watering is at all times necessary for small crops, although sometimes it is of the simplest character. Thus, at the base of the mountains scanty crops of grains can be produced by throwing up a series of ridges to retain the sheets of flood water that in winter occasionally sweep down over the land.

There is no reason to believe that in ancient times, when northern Africa was the granary of the civilized world, conditions as to water supply were essentially different from those now prevailing, although there is evidence that, in eastern Algeria at least, crops were much more extensively grown without irrigation than is now the case. Under the Carthaginian régime, and later under the Roman rule, irrigation works abounded in the country that is now Algeria and Tunis. The remains of such structures, sometimes utilized as foundations for modern works, are numerous, particularly in the Department of Constantine and in Tunis. Indeed, more than one region that is now a barren desert must have been well populated and in a high state of cultivation two thousand years ago.

The works built at that period were generally of the simplest and rudest construction. Often merely a mass of earth or broken stone, held in place by a row of stakes, served to dam a small brook. For the most part these structures were evidently the work of the colonists who tilled the land under them, rather than of trained engineers. They were built sometimes by individuals, sometimes by associations. The plan usually followed was to dam up a mountain torrent near the point where it debouches upon the plain. In narrow ravines a succession of rough dams was often constructed, thus allowing the stream to drop from terrace to terrace, leaving a tiny reservoir at each stage, from which water could be taken at need for irrigating small gardens and orchards. At the mouth of the ravine was a larger distributing reservoir, with a dam of stone and masonry, for diverting water into the irrigation canals, which branched out over the lower lands beyond. The safety of the larger dam was assured by the presence of these smaller reservoirs farther up the stream. By this method not only was water secured for irrigation, but the force of the current in times of flood was effectually checked. For a roaring, muddy torrent, sweeping all before it and carrying away great masses of the soil, was substituted a gentle stream of clear water, incapable of destructive erosion.

During the long centuries of Arab domination most of these irrigation works fell into ruin. Some, however, were patched up from time to time, and were used by the Arabs to irrigate their small fields and gardens. Soon after the French conquest the all-importance of some provision for the artificial watering of the land was perceived, and the construction of large storage and diversion reservoirs along Algerian streams was begun. At first this work was done by the engineer service of the French army.

COAST REGION.

Irrigation in Algeria to-day reaches its maximum development in the larger valleys and plains of the coast region. A number of important irrigation districts have been established, and reservoirs and canals have been constructed. At Marengo, on the Meurad, the first storage reservoir constructed by the French was finished in 1857. The dam, built of earth, is 266 feet long and 90 feet high. The barrage of the Cheurfas is built across the Sig, a short distance south of St. Denis du Sig. It took the place of a Turkish dam which was washed out in 1858. The present reservoir stores 2,400 acre-feet and supplies water for the irrigation of 5,000 acres in winter and 2,000 acres in summer. A larger dam, 6 miles farther upstream, was completed in 1884. This dam was of masonry, 98.4 feet high, 62.2 feet thick at the base, and 13.1 feet thick at the top. The capacity of the reservoir was calculated at 14,600 acre-feet. On February 8, 1885, the dam broke, carrying with it also that farther downstream. This break is said to have been caused by the infiltration of water through the rock around the dam. The foundation was of soft sandstone, in many places hardly sufficiently indurated to warrant its being called rock. The dam which was then built on the site of the older one is on the same general plan as its predecessor, but instead of being built on a straight line, the new portion is at an angle of 128 degrees with the old work, the angle pointing downstream. The object of constructing the dam in this way was to obtain a better foundation. It is reported that seepage around and under the walls of the structure still causes trouble, and some engineers question the permanent safety of the work.

The largest storage dam in Algeria is that across the Habra River, 7 miles south of the town of Perrégaux. This structure, also, has been the scene of a catastrophe, and a much more serious one than that which occurred at St. Denis du Sig. The original dam, 1,506 feet long, was built in two sections at an angle of 30 degrees, with the angle pointing downstream. It was partly carried away on December 15, 1881, by excessive floods which overtopped the entire dam. This disaster is generally attributed to the giving way of the soft foundation material, and to water cutting around the east end through the soft material. As a result of the break in the eastern end of the dam 400 persons were drowned and immense damage was done to property.

The work of reconstruction was finished in 1886. The dam, as it now exists, is essentially in three parts. The spillway on the west end has a length of about 410 feet. The center of the dam crosses an island which divides the stream into two channels. The portion of the dam across the east channel is 13 feet higher than that over the west channel. The reconstructed dam has a height of 131 feet, is 1,443 feet long, 131 feet thick at the base, and 14.7 feet thick at the top. The highest part of the dam, in the eastern section, consists of a wall 7.9 feet high and 4.9 feet thick, resting upon the top of the dam proper. This was added to prevent overflow of the adjacent land by floods. The event has shown the wisdom of this precaution, for in 1900 water rose to within 2 feet of the top of the highest wall, and was 6 feet higher than the crest of the spillway. The total cost of the Habra dam, from the inception of the enterprise, has been about $1,080,000.

The reservoir formed by this structure has a capacity of 30,800 acre-feet, and is intended to provide for the irrigation of about 100,000 acres, although so large an area has never been taken up under it. The water from the reservoir is taken out at the base of the high or eastern portion of the dam. A complicated apparatus has been devised by which water passing through the sluice furnishes power to pump water into a tank, which is situated upon a hill about 100 feet high at the east end of the dam. The water thus elevated furnishes stored power for the operation of the sluice gate. The gate is supposed to be automatically raised and lowered as the water rises and falls in the reservoir, but the mechanism has never proved altogether satisfactory.

The Habra, with its tributaries, has a flow in summer of 18 second-feet, but during unusual floods the discharge has been known to exceed 25,000 cubic feet per second. Although the drainage basin above the Habra dam covers 3,859 square miles, the mean annual discharge of the stream is estimated to amount to only about three and one-half times the capacity of the reservoir. During the flood which occasioned the breaking of the dam, caused by a 6½-inch rain over a great part of the watershed, the run-off in one night was more than three times the capacity of the reservoir.

Near the town of Relizane a small masonry dam has been built across the Mina River. This dam has a height of 45 feet above the the bottom of the rocky gorge in which it is built. It was originally planned to hold up a small storage reservoir, but this has become filled with sediment, and now the dam serves only for the direct diversion of the water of the stream. The discharge of the Mina is small. Though the canal system fed by this barrage covers an area of 20,000 acres, the land actually irrigated is not of large extent. The water of this stream, when examined toward the end of July, 1902, was found to carry 123 parts of soluble matter per 100,000 parts of water. Of this, 26 parts were bicarbonates, 1 part carbonate, 60 parts chlorids, and 36 parts sulphates.

Another masonry work of importance is that across the Djidiouïa River near St. Aimé, in western Algeria. It is 164 feet long, 55.8 feet high above the foundation, and 91.9 feet high, foundation included. The base has a thickness of 36.1 feet, and the top 13.1 feet. The reservoir has a capacity of 2,000 acre-feet, and is intended to irrigate from 7,500 to 10,000 acres.

Since it was built this reservoir has become almost completely filled with silt. In all reservoirs in Algeria the accumulation of silt has given trouble, but only at St. Aimé have attempts been made to remedy the evil. M. Jaudin, a hydraulic engineer, has invented a machine for stirring up and removing the silt. His apparatus consists of a metal tube or conduit 20 inches in diameter, the lower end of which penetrates the dam near its bottom. The free portion is kept afloat by buoys and is attached by flexible joints to a floating scow. The connections are made so as to allow the scow to float from side to side of the reservoir, and the end of the pipe can be raised and lowered as desired. The difference in level between the end of the pipe projecting through the dam and that attached to the scow produces a strong current through the pipe. As the pipe is moved along the mud is sucked into it and is carried below the dam. The clay drawn into the pipe is found to be so well packed and so stiff that it has to be cut out by a special cutting apparatus built like a steam screw. In spite of the cutting apparatus, the water thus removed carried only from 4 to 5 per cent of silt. The inventor claims that under favorable conditions he can remove water containing 16 per cent of silt. The expense of operating the apparatus is estimated at $35,000 a year, and the cost of installation for a fairly large dam would be $540,000. The inventor was under contract to remove the silt from this reservoir at 20 cents per cubic meter (15.4 cents per cubic yard).

In the Mitidja Valley, near Algiers, there is a reservoir which is capable of holding about 11,340 acre-feet of water. This is sufficient to irrigate 75,000 acres, but the area actually under irrigation is only one-third as large.

The irrigation works just described are more or less typical. At a number of other places dams are either in actual use or are under construction. Algeria has been unfortunate in regard to disasters to her irrigation works. This has tended to create distrust of them among farmers who practice irrigation. There were lean years for people who tried to farm below the canals while new works were building, and the memory of those trying times is still vivid. It seems that in the early days of colonization too much land was covered by the irrigation works. Consequently, there are now large uncultivated areas across which the canals and laterals have to be extended in order to reach land that is in crops.

There is reason to believe, as an eminent authority upon agriculture in Algeria has remarked, that more good might result from the construction of series of irrigation works on a small scale, after the fashion of the Carthaginian and Roman colonists, than from the building of elaborate engineering works such as have just been described. The peculiar torrential character of Algerian streams and the great quantity of silt they carry make them ill adapted to large structures of this kind; but small diversion reservoirs, that afford water only in winter, are a valuable supplement to the natural rainfall, particularly in the drier western part of the coast region. There it is found that one or two irrigations during the winter will very materially increase the yields of cereals and forage crops. Handled thus, with two irrigations in winter, an acre of wheat in the Chéliff Valley can sometimes be made to yield 44 bushels.

The most important direct diversion of water from a stream in Algeria is that on the Chéliff, 15 miles above Orléansville, where the irrigating water is taken from the west bank of the river by means of a canal with a capacity of about 50 cubic feet per second. One branch of this canal is carried across the river by a siphon to irrigate the right bank. On the left bank 6,000 acres, and 19,000 acres on the right bank, are irrigated by this canal. The entire system cost about $480,000. Those who use the water are required to construct the secondary canals, pay a rental to the government, and keep the works in repair. Of the 50 cubic feet of water per second available under this system, 13 only have been subscribed for, on account of the excessively high water rent asked. Similar difficulty in inducing farmers to subscribe to water at the rates demanded has been encountered elsewhere in the colony.

In the mountain zone, notably in Great Kabylia, there are many small diversion dams, cheaply constructed in narrow ravines out of such materials as are ready to hand. By means of these, streams that in summer appear to be dry, but really carry subterranean water, are made to serve for irrigation at that season. The bed is dug out until rock bottom is reached. A dam is then roughly fashioned out of stones. The trunk of a tree is laid across the top, which is slightly higher than the general level of the stream bed, and clay and stones are piled up behind the dike; or, sometimes, a mere double row of stakes, filled in with clay and stones, is made to answer the purpose.

Various devices are in use in Algeria for preventing water that falls upon cultivated hillsides from running off too rapidly. Particular attention has been paid to this question in vineyards. Sometimes shallow basins are dug in the center of each quadrangle formed by four vines. Another practice, which is also followed by the Kabyles in their orchards, is to run horizontal furrows or trenches across the hillside at regular intervals, throwing out the soil on the downhill side. It has been estimated that, at a cost of about $3, from 9,000 to 10,000 cubic feet of water, enough to cover the land to a depth of from 2 to 4 inches, can thus be saved annually in each acre of vineyard. In olive orchards, which cover steep hillsides in some parts of the colony, V-shaped trenches, pointing downhill, are dug so that the point of a trench is situated near the base of each tree. The soil around the tree is kept loose in order to facilitate absorption of the water thus carried to it.

The market gardens of the littoral zone are generally irrigated by means of the "noria," a water-lifting machine that has been in use for ages in the Mediterranean region. It consists of a vertical wheel, to the rim of which buckets are attached, and which turns by interlocking its cogs with those of a horizontal wheel. To the latter an animal, usually a horse or a donkey, is hitched, and is driven around in a circle. A second animal is kept to relieve the first, generally every two hours. By means of the noria one horse can raise 150 gallons of water 11 feet in a minute, which is equivalent to 0.33 second-foot. The water is collected in a basin that generally holds from 1,000 to 1,800 cubic feet. Even field crops and vineyards can be profitably irrigated with the noria if the water supply is ample and the lift does not exceed 40 feet. But its greatest usefulness is in connection with the intensively cultivated and very remunerative truck crops. The noria is said to be more economical for raising water than any hydraulic machine, only one-fifth of the total power expended being lost. Near Algiers, where the irrigation of gardens is most expensive, the annual cost of watering 1 acre with the noria is placed at $65.

The water used for irrigation in the coast region, except in some of the valleys of western Algiera, is generally very good, rarely containing a harmful quantity of salts. However, no attention has been given to the matter of drainage of irrigated lands. Particularly in western

Algeria, large areas of once fertile soil have in consequence become subirrigated and salty. In many cases considerable tracts have had to be abandoned for this reason.

HIGH PLATEAU REGION.

A very insignificant area is irrigated in the high plateau region. There are almost no running streams, except after an occasional heavy rain in winter. The water of the chotts or lakes that fill the depressions is far too salty to be used for irrigating purposes. Here and there a small patch of grain, forage plants, or garden vegetables is watered from a well, but artesian water seems to be generally lacking.

DESERT REGION.

Oases of greater or less extent occur in all parts of the Sahara. They are particularly numerous, however, in the lower eastern portion. In the region known as the Oued Rirh, a larger percentage of the total area is occupied by cultures than anywhere else in the desert. The oases (see Pl. I), almost without exception, are probably of artificial origin. The date palm, to which they owe their life, is believed to have been introduced into Algeria by man. In some places near the base of the mountains, as in the region of the Zibans, there is flowing water on the surface of the ground which can be diverted directly into canals. At most, a few rude dams are needed to raise its level a few inches. Elsewhere wells must be dug and the water must generally be raised by hand or by the noria in order to water the crops. The source of the water thus utilized is to be looked for in the high mountains adjacent to the Sahara, where the rainfall is much heavier than in the desert itself. This water flows down to the lower levels, at first over the surface of the ground, then beneath it. Subterranean streams of considerable volume must occur in the eastern part of the Sahara. There is no foundation for the idea sometimes entertained that the oases are natural subirrigated spots in the desert. Most of the desert soils are too saline to permit of subirrigation without injury to the crops. As a matter of fact, agriculture would be almost impossible in the Sahara were not careful provision made for drainage.

From very ancient times irrigation has been practiced in the desert. When the Romans governed northern Africa the area under cultivation in the Sahara was much larger than it is to-day. By many centuries of practice the natives of the Sahara have acquired great skill in procuring and managing water for irrigation. The art of well boring, as originally practiced in the Oued Rirh, is a dangerous one. The work is begun by scooping out a hole in the sand, the sides of which are incased with wood as fast as the digging proceeds. Finally, a layer of rock or of stiff clay, overlying the sheet of water, is reached.

This is broken through with a few strokes of the pick, and if the water ascends with considerable force, as is sometimes the case, the well digger runs considerable risk of being drowned. In the more accessible parts of the Sahara, modern well-boring machinery has largely replaced the ancient method.

The natives are very jealous of the water that is obtained with so much difficulty, and numerous quarrels arise over its distribution. In the Zibans oases, where a system of canals exists, the water is controlled by an association which decides in what quantity and upon what days it shall be allotted to each person. It is measured by laying the trunk of a date palm across the top of an earthen dam in the canal. Notches, corresponding to the width of the hand with the thumb closed, are cut into this trunk at intervals. The amount which passes each of these notches represents one share of water.

In the Oued Rirh region, since the French occupation, a great many artesian wells have been bored, under the direction of M. Jus, who became famous through his connection with this work. The first was sunk in 1856. In 1898 there were 120 metal-cased artesian wells from 160 to 330 feet deep, in addition to 500 wells dug by natives. The total discharge of all these wells was about 140 cubic feet per second, yet so far the water supply has suffered no perceptible diminution. With the water thus obtained the area in date palms has been greatly extended during the past thirty years. It is estimated that during the last three decades the population of the Oued Rirh has doubled, and the wealth of the region has been increased tenfold. There are probably few other parts of the Sahara where such development is possible.

Unlike the irrigating water of the coast region, that used in the desert region generally carries a high percentage of salts in solution. In fact, the water with which various crops are grown in the Algerian Sahara appears to be saltier than that used for this purpose anywhere else in the world. So far as is known, 500 parts of salts per 100,000 parts of water is the maximum concentration of water which is used with success in the United States, and, under ordinary circumstances, 300 parts is the limit for successful crop production. In the Sahara, however, water containing as much as 800 parts of salts (half of the total amount being sodium chlorid) per 100,000 parts of water is applied to soils that are themselves highly saline. A variety of cultivated plants various fruit trees, garden vegetables, and alfalfa thrive under these conditions.

It seems a fair inference that the maximum amount of soluble matter which can safely be allowed in irrigation water has been underestimated by American writers. Where the soil is light and underdrainage is provided for, as is the case in the Algerian oases, it is probable that many waters that have heretofore been condemned as too saline could safely be used in irrigating crops.

The date palm is the most salt-resistant cultivated plant of the Sahara, so far as is known. The maximum amount of salt in the irrigating water which this tree can endure without detriment to the crop has not been ascertained. It would appear, however, to be something less than 1,000 parts per 100,000, for water of a pond containing 1,044 parts per 100,000 of soluble salts, of which 1,036 parts was sodium chlorid, had been found to be too salty for irrigating a young date orchard.

A number of samples of artesian water used in irrigating the oases near Tougourt, in the Oued Rirh region, were taken by the writers and were analyzed in the laboratory of the Bureau of Soils of the Department of Agriculture. The results are stated in the following table:

TABLE 6.—*Chemical analyses of artesian water used in irrigating gardens in Saharan oases, Algeria.*

Constituent.	Well at Oasis Tabes-bes.	Well at Oasis Kudi Asli.	Well at garden of Ben Hadriah.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	9.92	4.19	9.86
Magnesium (Mg)	4.52	6.02	4.26
Sodium (Na)	14.03	20.48	14.18
Potassium (K)	4.27	2.35	2.72
Sulphuric acid (SO_4)	34.38	29.43	17.59
Chlorin (Cl)	28.06	36.21	27.05
Bicarbonic acid (HCO_3)	5.02	1.32	24.34
Conventional combinations:			
Calcium sulphate ($CaSO_4$)	33.04	14.23	24.90
Magnesium sulphate ($MgSO_4$)	13.63	24.29	7.04
Magnesium chlorid ($MgCl_2$)	7.23	4.41	16.72
Potassium chlorid (KCl)	8.12	4.48	5.19
Sodium bicarbonate ($NaHCO_3$)	6.92	1.81	33.54
Sodium chlorid (NaCl)	31.06	50.78	12.61
Total solids in 100,000 parts water	601.50	408.10	571.90

These are fair average samples of the irrigation waters in use, and do not represent by any means the maximum of salinity. Field tests showed as high as 816 parts to 100,000 in water in actual use on soils where garden vegetables were growing, while French authorities report the use of waters carrying 842 parts per 100,000.

SOILS.

The soils of Algeria are of many varieties and types, varying from the coarsest sands to heavy clays. The differences are due chiefly to two causes—the nature of the underlying rocks and the climatic conditions under which the soil was formed. Different classes of soils are found in each physiographic region and there are few types which are common to all three regions. In the littoral zone of the coast region much of the soil is of the adobe type, containing a considerable quantity of clay. In the alluvial bottoms, however, we find extensive areas of other kinds of soil. In the mountain zone the soils are not for the most part adobe-like. On the high plateau the soils are largely colluvial. In the desert we encounter vast areas of light, sandy soils, but there are also extensive tracts of marls, clays, and alluvial soils.

Very few samples of soil were collected, as no general investigation of the various types was attempted by the writers. It was observed, however, that in Algeria there appear to be no important soils which are not represented in California and Arizona by very similar types. Observations were largely directed toward the comparison of Algerian soils and their productivity with corresponding soils in America under similar climatic conditions.

COAST REGION.

LITTORAL ZONE.

An important and characteristic soil of the littoral zone is a bright-red "adobe," very common in the vicinity of Algiers, near Oran, and elsewhere along the coast. It is sticky when wet and forms very hard clods when dry, cracking to a depth of from 12 to 24 inches. This soil is often naturally poor in phosphoric acid, nitrogen, and lime, but responds readily to treatment. Its potash content is generally adequate. It is an excellent soil for vineyards, except in cases where a lime "hardpan" occurs too near the surface. Some of the best wines of Algeria are produced on soil of this type. The American soils which most nearly resemble it are the San Joaquin red adobe, as it occurs in the San Joaquin and Sacramento valleys, and the Fullerton sandy adobe of the coast region of southern California.

A mechanical analysis of one specimen of this soil is given on page 40, under No. 7663. This sample was collected a few miles south of Oran, and represents the heaviest phase of this red soil. We have not found in America a type of red adobe in which the average clay content is so high. The black adobes of the United States are sometimes very clayey, but most American adobes contain more silt than clay. The same soil type was also observed at Arzeu, in western Algeria, at various localities near Algiers, and, to a less extent, around Tizi Ouzou, in Great Kabylia.

River bottoms in the littoral zone are characterized by soils that are quite different from the red, clayey type just described; and are, in fact, mere continuations of the soils of the next zone. They are usually alluvial deposits, clayey or marly in texture, and are quite fertile. They contain an abundance of potash, though they are sometimes deficient in phosphoric acid.

VALLEY AND PLAIN ZONE.

The large valleys, which in some cases are so extensive as to be virtually plains, contain a great variety of soils. The plains of the

Mitidja, Chéliff, Mina, Habra, and Macta are typical of many other valleys and plains in Algeria. As before mentioned, they are similar in many ways to the interior valleys of California. The soils are mainly alluvial and are generally heavy. Around Relizane and Perrégaux, where the writers made most of their studies, the soil is similar to the San Joaquin black adobe. In the Mitidja the heavier soils are well supplied with potash and are fairly well provided with nitrogen and phosphoric acid. In the Chéliff Valley these elements are less abundant.

Sample No. 7658, in the table given below, shows the results of a mechanical analysis of the heaviest of the valley adobes. This sample was collected from a field which was very fertile twenty years ago, but which has since been ruined by the rise of salts, and is to-day valueless. This soil, before it had become saline, had exhibited great fertility during a long series of years. In former years it yielded grain of a superior grade and good crops of cotton. Sample No. 7660 represents a type of this adobe soil of medium heaviness. Soil of this kind is often planted to vines, fruits, and olives. The sample was collected near Perrégaux, at La Ferme Blanche, headquarters of one of the largest vineyards in Algeria. A still lighter type, one closely approaching a sandy loam, is represented by sample No. 7661. This type is usually found in the higher portions of the valleys, and is planted to vines and alfalfa.

MOUNTAIN ZONE.

The soils of the mountain zone of the coast region can be divided into (1) valley soils and (2) soils of the hills and mountain slopes. The hills and mountains are covered with either residual or colluvial soils. As a rule, these soils are more or less gravelly or stony, and are light and well drained. The lower slopes frequently have heavier adobe soils, similar in character to the adobes of the lower slopes of the Sierra Nevada and the coast range in California.

The soils of valleys in the mountain zone are generally alluvial, being composed of the waste from adjoining hills and mountains. The smaller valleys have light, usually well-drained, soils containing some gravel.

TABLE 7.—*Mechanical analyses of coast region soils.*

No.	Locality.	Depth in inches.	Organic matter.	Gravel, 2–1 mm.	Coarse sand, 1–0.5 mm.	Medium sand, 0.05–0.25 mm.	Fine sand, 0.25–0.1 mm.	Very fine sand, 0.01–0.05 mm.	Silt, 0.05–0.005 mm.	Clay, 0.005–0.001 mm.
7658	Relizane	0–24	0.01	......	0.08	0.12	0.66	2.00	40.22	56.92
7660	La Ferme Blanche, near Perrégaux	0–24	.22	......	.08	.10	2.00	20.14	54.66	22.94
7661	Debrousseville	0–12	1.34	0.16	1.08	3.06	28.60	30.62	20.40	16.08
7663	2 miles south of Misserghin	0–18	1.41	.12	.58	1.94	6.60	6.36	35.76	48.64
7688	15 miles east of Batna	......	......	.32	.28	.34	1.74	6.04	45.56	45.48

HIGH PLATEAU REGION.

The soils of this region, derived largely from cretaceous and tertiary rocks, are in great part alluvial deposits washed down from the neighboring mountains. Particularly in eastern Algeria, soils very rich in phosphates occur. These would be extremely fertile if water wherewith to irrigate them were available. Calcareous hardpan underlies a great deal of the surface of the high plateau. Where this impervious layer is quite near the surface the vegetation is sparse and woody plants are absent.

The high plateau soils grade from stony soils on the lower slopes of the mountains, through sandy loams and loams, to heavy clay loams and clays in the bottoms of the depressions. These depressions, known among the Arabs as "chotts," are a conspicuous feature of the steppes. While occasionally filled with water, the bottom is commonly dry and covered with a layer of salt. The chotts greatly resemble the "playa" lakes of the Great Basin region in Utah and Nevada and of the "bolson" plains of the southwestern United States and Mexico. The soil in the bottom of the chotts is always heavy and impervious.

DESERT REGION.

The soils of the western part of the Algerian Sahara—which is of very little agricultural importance—more or less resemble those of the very arid parts of the high plateau. In the eastern part of the desert, where numerous oases occur, the character of the soil becomes a matter of greater practical interest. The combined area of all the oases amounts to but a small fraction of 1 per cent of the total surface of the desert. The limited localities where oases occur are determined by the presence of water rather than by any exceptional fertility of the soil. As a matter of fact, there are vast tracts in the Sahara which are, probably, naturally more fertile than the oases and require only water to make them extremely productive.

The field observations made by the writers were confined to a number of typical areas in the Oued Rirh country. There are found the most important oases that are easily accessible from the Mediterranean coast. They are situated in what is probably the hottest part of the desert and their elevation above sea level is only a few feet. In fact, several of the oases occur in a part of the basin that is below sea level.

As a rule the soils of the oases in the eastern Sahara are light in texture. Sandy loams and sands predominate, though here and there are found soils heavy enough to be classed as true loams. Gypsum is an important constituent of nearly all the soils examined, in some cases the subsoil being practically pure gypsum. This often acts as a cementing material, uniting the finer soil grains into aggregates which give the soil a much more sandy appearance than would be suspected from the results of mechanical analyses. The data afforded by a number of analyses are given below.

The natural fertility of these sandy soils is not great. They are almost devoid of organic matter and after a few years of cultivation need fertilizing. This is supplied by the Arabs in the form of manure from donkeys, sheep, and camels. The soils of the date orchards that have been planted by the two French companies are also fertilized.

The following table gives the results of mechanical analyses of a number of samples of soil collected in the Oued Rirh region of the eastern Sahara. Chemical analyses have not been carried further than a determination of the water-soluble material.

TABLE 8.—*Mechanical analyses of soils from the Oued Rirh region in the Sahara Desert.*

No. of sample.	Locality.	Depth in inches.	Organic matter.	Gravel, 2-1 mm.	Coarse sand, 1-0.5 mm.	Medium sand, 0.5-0.25 mm.	Fine sand, 0.25-0.1 mm.	Very fine sand, 0.1-0.05 mm.	Silt, 0.05-0.005 mm.	Clay, 0.005-0.001 mm.
7686	Ourir. Hard crust among palms	0-12	0.76	0.52	1.76	3.74	21.02	18.98	21.98	31.26
7687	Subsoil of 7686	12-26	.34	.20	1.88	1.84	29.52	21.42	15.48	29.40
7683	Ourlana palm orchard	0-12	.50	.54	.90	1.14	17.46	49.80	11.64	9.16
7684	Subsoil of 7683	12-36	.08	.48	1.64	3.70	46.84	29.30	7.64	9.92
7685	do	36-54	.04	.86	2.50	2.84	18.74	36.40	19.40	9.14
7665	Ourlana among 13-year-old palms	0-12	.14	2.46	3.96	8.06	32.52	33.56	5.42	14.02
7666	Subsoil of 7665	12-36	.04	1.10	4.46	5.74	31.70	40.94	4.52	11.54
7667	Tougourt amid good alfalfa	0-12	1.10	.20	1.32	3.98	31.44	37.98	9.52	12.56
7668	Subsoil of 7667	12-24	.59	.16	1.30	3.06	28.58	45.92	8.72	12.12
7669	Tougourt amid alfalfa	0-12	.73	.15	1.93	4.63	27.71	33.59	7.98	24.01
7670	Subsoil of 7669	12-24	.62	.73	2.51	5.37	32.12	33.27	5.85	20.15
7671	Tougourt amid alfalfa	0-12	1.47	.26	2.01	4.98	28.22	30.91	11.21	22.41
7672	Subsoil of 7671	12-24	1.35	.12	1.41	4.07	28.33	29.82	7.54	28.71
7673	Ta-bes-bes Oasis	0-12	.41	1.56	2.03	1.72	20.24	32.53	6.37	35.55
7674	Subsoil of 7673	12-24	.16	.35	1.27	1.33	25.94	34.40	6.57	30.14
7676	Kuda Asli Oasis	0-12	.66	1.12	4.76	6.75	28.58	32.60	7.97	18.22
7677	Subsoil of 7676	12-24	.35	1.39	3.27	4.39	20.38	26.42	15.76	28.39
7678	Dune sand, border of Djadja Chott	....	.47	.00	5.08	12.80	51.54	18.40	1.22	7.62
7679	Oasis of Zoia de Temacin	0-12	6.30	.86	4.60	4.66	22.50	17.48	26.90	9.04
7680	Subsoil of 7679	12-24	.27	1.50	5.14	5.90	19.60	20.24	25.88	8.82
7681	Oasis of Zoia de Temacin	0-12	.44	1.54	6.16	4.24	22.70	39.10	14.50	5.76
7682	Subsoil of 7681	12-24	.21	.09	4.54	2.60	19.12	30.94	20.78	10.60

SALINE SOILS.

As in all arid countries, particularly where irrigation is practiced, saline soils are an important factor in the agriculture of Algeria. Extensive areas of the most fertile land of the colony have been injured by an excess of salts, and the alkali problem is to-day one of the most serious which confronts the Algerian farmer. Drainage is not generally practiced by the colonists in their large irrigation districts, and the lack of it has been the cause of a great deal of damage. On the other hand, the natives of the Sahara show the utmost ingenuity and skill in managing salty soils and in irrigating with saline waters. There is much in the methods practiced by these people that should interest the American farmer and that could be imitated by him with profit.

COAST REGION.

The littoral zone of the coast region comprises very little alkali or saline land. A few areas of salt marsh occur along the shore, but not much has been done toward their reclamation.

The most extensive areas of salt soil in the coast region are those found in the great valleys and plains. Certain of these areas have existed for a long time. Others, including some of the most serious, have been developed under irrigation within the last fifty years. The most important tracts of salt land seen by the writers were near the towns of Relizane and Perrégaux, in the Department of Oran.

At Relizane the area covered by the irrigation systems amounts to about 20,000 acres. As the water supply very frequently falls far short of the amount necessary for the irrigation of this large area, part of the land is ordinarily lying idle. The irrigation of surrounding fields, together with seepage from the canals and laterals, has so raised the water table in this uncultivated land as to permit a constant upward movement of the water by capillary force. The result has been that salts which were formerly confined largely to the subsoil, or which have been carried into the soil by subirrigation, have risen to the surface and have accumulated there. The same process of accumulation of salts in the upper layers of the soil has caused serious damage in many parts of western North America. Around Relizane the old story has been retold that land once fertile and producing luxuriant crops is to-day bare of everything but a few stunted salt-loving weeds. The remains of irrigating laterals, fences, and houses alone show that the land has ever been farmed.

At Perrégaux a similar state of affairs prevails, but a much larger area is affected. The salt land covers an extensive tract in the lower part of the valley and includes fields that a few years ago were highly productive. A few attempts at reclamation have been made, and some excellent fields were seen which were said to have been badly saline at one time; but no large areas have been improved.

The soil and other conditions of saline areas in the irrigated districts of Algeria have no important peculiarities which distinguish them from similar localities in America. The salts are generally "white alkali," i. e., salts of sodium (other than the carbonate), magnesium, and lime.

Chemical analyses of samples of these soils taken by the writers are given on page 46. The predominant salts are of the "white alkali" type, common salt (sodium chlorid) being the most abundant. Very little "black alkali" (sodium carbonate) has been found in the coast region of Algeria.

The question of salt land in Algeria has been discussed in a recent publication by Dugast, who devotes particular attention to the damage that has been wrought in the vineyards of western Algeria by the rise of salts in the soil. We may be excused for quoting at some length from this author.[a]

> It is sea salt—that is, true salt—that is generally found in Algeria, but magnesium salts have also been found in several vineyards. As for the alkali salts, or "black alkali," we have not yet come across them. They probably appear, however, when circumstances favorable to their formation exist. * * * But if their existence is transient, if washing does not take place to separate them from the other salts, it is difficult to determine their presence.
>
> In 1876 Pichard called attention to the presence of carbonate of sodium in several waters in Oran Department, accompanied by sulphates of sodium and calcium and chlorids of calcium and magnesium, sometimes by small quantities of alkali nitrates and traces of ammonium salts. These waters give an alkaline reaction and contain from 0.2 gram to 20 grams of sodium carbonate per liter.
>
> While the salt is directly harmful, it is also indirectly injurious by hindering the nitrification of the nitrogenous matter existing in the soil or added to it by manure. Hence it interferes with the alimentation of plants.
>
> In vineyards salt manifests itself in spots which differ in aspect according as they are old or new. When the salt is in small quantities in the soil, or, rather, when the soil still contains a considerable proportion of water, or when, again, the salt reaches only a part of the zone of soil occupied by the roots, the spots are characterized by a simple wilting of the vegetation.
>
> At other times the damage caused by the salt is sudden and much more pronounced. The places attacked then take the form of circular spots. The branches of the vines that bear grapes lose their leaves and dry up, and the grapes do not reach complete maturity.
>
> In 1898 and in 1899, at the time of our visit [to the vineyards of Oran Department], we saw numerous spots presenting these characteristics. Such spots were occupied by vines loaded with grapes, but the branches had completely lost their leaves. All around them the vines were green and were well loaded with a good crop of grapes.
>
> In the older spots, which are sometimes very extensive, most of the vines are dead. We find, however, here and there, some vines that have resisted the salt and have been able to put out badly developed branches bearing a few grapes of poor quality. These old spots, although due to salt, much resemble those caused by phylloxera.
>
> The reclaiming of salt land is difficult to accomplish in Algeria. The rainfall is always insufficient to bring about reclamation, and the supply of irrigation water is also scanty.
>
> For the present we must try to get along with the salt, doing our best to prevent its becoming too injurious. This can be done by working the soil to a depth of 20 inches, so that the rain water can be stored in that depth of the soil. In this way the fresh water can be prevented from penetrating sufficiently deep to dissolve the salt and by its presence it restrains the salt from rising. It is necessary, of course, by superficial cultivation to break up the capillarity of the soil, so as to reduce evaporation to a minimum.
>
> Drainage ditches can also be used in certain lands for carrying off the salty water of the lower depths of the soil. Ditches can also be used in certain cases to prevent the invasion of new land by the sheet of salt water.

Saline soils of purely natural origin are found in and near the chotts which occupy depressions and receive the drainage of the surrounding land. In such places salt has been accumulating through long ages.

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[a] Agrologie de l'Algérie, 1900, pp. 56, 58, 59, 71, 72, 77, 78, 80, 81, 89, 90.

In the dry season the bottom of the basin is covered with a crust of salt, in some cases of sufficient thickness to make its exploitation profitable. In the wet season this gives place to a shallow lake of salt water. A number of such chotts occur near the coast in western Algeria. The writers visited one large salt lake near Arzeu and another near Oran. At the Salines d'Arzeu great quantities of commercial salt are prepared. These chotts correspond to similar salt, soda, and "playa" lakes of Utah, Nevada, and other western States.

Many salt lakes also occur in the high plateau region. In the eastern part of the Sahara the chotts cover extensive areas south of Tunis and of the Department of Constantine. There they are below sea level, and the country around them is very hot and dry.

DESERT REGION.

The saline soils of the Oued Rirh region in the Sahara, so far as they were examined by the writers, generally contain a large amount of gypsum. (See p. 46.) Sodium chlorid and sodium sulphate are the next most abundant salts, while magnesium salts are present only in small quantities. The Saharan soils are usually of very light texture, and their proper irrigation demands large quantities of water. The water used contains a high percentage of soluble matter. Consequently, where proper drainage facilities have not been provided, the salt has accumulated in the soil to an injurious degree. Yet, by digging open drains 3 feet deep at frequent intervals and irrigating once a week or oftener, the natives of the Sahara are able to maintain gardens containing a variety of plants not particularly resistant to salts in the soil.

More than this, using strongly saline water (see p. 38) they are able to reclaim land that contains an excessive amount of salts. The writers visited a garden which had been established on the slope of the bed of a salt lake, in which alfalfa, various garden vegetables, and a variety of young fruit trees were flourishing. The reclamation of this piece of land had been accomplished in three years by irrigating twice a week during that period.

TABLE 9.—*Chemical analyses of saline or "alkali" soils from Algeria.*

No. of sample.	Locality.	Depth in inches.	Calcium (Ca).	Magnesium (Mg).	Potassium (K).	Sodium (Na).	Sulphuric acid (H_2SO_4).	Chlorin (Cl).	Bicarbonic acid (HCO_3).
7658	Relizane, 3 miles NW	0–24	7.28	4.53	3.08	18.48	27.31	34.22	5.10
7659	do	0–1	2.41	12.15	1.10	15.83	9.70	56.86	1.95
7665	Ourlana, among 13-year-old palms	0–12	23.27	.91	1.92	4.77	59.13	8.35	1.65
7666	do	12–36	23.46	.49	2.24	4.33	65.30	2.09	2.09
7667	Tougourt Oasis, amid good alfalfa	0–12	23.81	.89	1.82	3.52	66.22	1.87	1.87
7668	do	12–24	25.23	.66	1.51	2.63	65.96	1.87	2.14
7669	Tougourt Oasis, amid poor alfalfa	0–12	23.90	.88	1.82	3.28	66.49	1.24	2.39
7670	do	12–24	24.71	.58	1.76	2.84	66.69	1.26	2.16
7671	Tougourt Oasis, amid yellowing alfalfa.	0–12	23.72	1.13	1.68	3.90	61.35	6.46	1.76
7672	do	12–24	24.67	.68	1.93	2.86	66.28	1.76	1.82
7673	Ta-bes-bes Oasis, amid alfalfa	0–12	20.27	1.61	2.10	1.34	61.38	4.96	3.34
7674	do	12–24	19.11	1.53	1.94	7.84	61.13	5.27	3.18
7675	Kuda Oasis	Crust.	.56	.66	.29	37.03	3.82	56.99	.65
7676	Kuda Asli Oasis, amid good alfalfa	0–12	16.03	3.27	4.47	6.86	56.18	7.96	5.23
7677	do	12–24	19.75	1.96	2.49	6.03	61.83	4.79	3.15
7679	Zoia de Temacin Oasis, amid good alfalfa	0–12	22.83	1.21	1.56	4.51	63.90	4.02	1.97
7680	do	12–24	24.00	1.05	.76	3.92	65.30	2.95	2.02
7681	Zoia de Temacin Oasis, amid yellowing alfalfa	0–12	22.72	.97	1.94	4.90	61.66	5.08	2.73
7682	do	12–24	24.01	1.17	1.48	3.33	64.79	3.60	1.62
7683	Ourlana, among 20-year-old palms	0–12	23.38	1.04	.92	5.15	59.47	8.54	1.50
7684	do	12–36	26.08	.98	.85	2.15	64.97	2.82	2.15
7685	do	36–54	23.06	.99	.99	4.92	63.74	3.71	2.59
7686	Ourir, among palms	0–12	16.73	4.11	1.77	10.89	24.13	41.35	1.02
7687	do	12–26	23.84	1.20	1.16	3.90	62.10	5.81	1.99

TABLE 10.—*Conventional combinations of the data in Table 9.*

No. of sample.	Percent soluble matter.	Calcium sulphate ($CaSO_4$).	Magnesium sulphate ($MgSO_4$).	Magnesium chlorid ($MgCl_2$).	Potassium chlorid (KCl).	Sodium chlorid (NaCl).	Sodium bicarbonate ($NaHCO_3$).	Sodium sulphate (Na_2SO_4).	Other constituents.
7658	2.47	24.78	12.31	7.93	5.99	41.95	7.04		
7659	6.14	8.17	4.91	43.78	2.11	38.36	2.67		
7665	4.36	79.23	4.03	.18	3.67	10.65	2.24		
7666	4.02	79.69	2.44		4.23	.15	2.88	10.61	
7667	4.49	80.88	4.42		3.56	.32	2.58	8.24	
7668	4.48	85.69	3.30		2.90	.80	2.94	4.37	
7669	4.50	81.24	4.39		2.57		2.17	8.35	[a] 1.28
7670	4.43	84.39	2.89		2.66		2.21	6.95	[a] .90
7671	4.76	80.61	5.58		3.19	8.19	2.43		
7672	4.62	83.75	3.42		3.70		2.50	6.63	
7673	3.25	68.89	7.93		4.03	5.03	4.58	9.54	
7674	3.39	64.97	7.55		3.71	5.72	4.36	13.69	
7675	92.93	1.91	3.07	.16	.55	93.42	.89		
7676	1.83	54.42	16.03		8.50	6.43	7.19	7.43	
7677	3.05	67.01	9.64		4.72	4.20	4.33	10.10	
7679	4.87	76.64	6.03		2.95	4.35	2.71	6.32	
7680	4.72	81.65	5.19		1.43	3.76	2.78	5.19	
7681	3.50	77.01	4.79		3.71	5.48	3.76	5.25	
7682	4.44	81.64	5.54		2.83	3.69	2.20	1.10	
7683	4.77	79.48	4.19	.79	1.76	11.73	2.05		
7684	4.46	87.17	4.87		1.61	3.40	2.95		
7685	4.63	78.37	4.92		1.90	4.62	3.51	6.65	
7686	6.99	31.20		16.13	3.37	26.55	1.40		[b] 18.35
7687	4.82	80.99	5.93		2.20	7.85	2.74	.29	

[a] Potassium bicarbonate ($KHCO_3$).

[b] Calcium chlorid ($CaCl_2$).

SOIL MANAGEMENT.

ROTATIONS.

In the grain-producing districts of Algeria the rotation—if it can be called such - commonly followed consists of a year (winter) in a cereal crop followed by a year of fallow. In other words, the land lies idle for sixteen or eighteen months out of twenty-four. This system was followed by the ancient Greeks and Romans, and is still in vogue among their descendants in the Mediterranean region. It is to be recommended only for countries where the rainfall and the supply of irrigating water are too scanty to permit rotation with a soil-restoring crop and where manure can not be had in any considerable quantity. Such is the case in the most important cereal-growing districts of Algeria. A larger net profit is often obtained from 2 acres of grain managed in this way than from 1 acre that is heavily manured. If deep and thorough plowing is included in this method of handling the soil, the benefit to the land that would accrue from the use of another crop in rotation can be partly compensated for.

No leguminous crop has yet been found which can be profitably grown on a large scale in Algeria in rotation with wheat and barley. The scarcity of irrigating water is chiefly responsible for this condition, and wherever water is abundant the question of rotation ceases to be a troublesome one. In that case a crop of horse beans or vetch—or, if manure is obtainable, of beets, potatoes, or tobacco—followed by two crops of grain is found to make a satisfactory rotation.

FERTILIZERS.

Whatever may have been their natural condition, the cropping of Algerian soils for thousands of years, often without intelligent effort to conserve their fertility, has resulted in greatly impoverishing them. In large areas the soil is low in phosphates and, to a greater or lesser extent, in nitrogen. Potash, on the other hand, is generally sufficiently abundant. In the coast region much of the soil can be benefited by liming.

During the first few years after the French conquest no particular attention was paid to questions of fertilizers and of rotation. Soon, however, under the influence of the more intensive farming practiced by Europeans, the yield of crops began to diminish, and it became necessary to look for a remedy. In the littoral zone of the coast region, where there is intensive cultivation of market gardens, orchards, and vineyards, the use of farm manure and of commercial fertilizers has become general. In 1896 the annual consumption of Algerian phosphates alone in the colony had reached 8,000 tons. In 1900 the total quantity of mineral fertilizers applied yearly to the soils of Algeria was estimated at 15,000 tons. The use of mineral fertilizers is limited almost entirely to the littoral zone.

In the large valleys of the coast region, where vineyards and fields of grain cover extensive areas, it is estimated that not one-twentieth of the total amount of cultivated land is given any fertilizer whatever. The supply of farm manure is exceedingly scanty, as the absence of cultivated forage crops prevents the raising of many cattle. Where farm manure is obtainable it is thought to be more beneficial than any commercial fertilizer, since Algerian soils are often deficient in organic matter and manure has a very beneficial physical effect upon them. It is considered good practice to apply manure in the autumn, after a year of fallow, thus obtaining an abundant crop of wild forage the following winter. Grain is then grown during the second and third winters after the application of manure.

PREPARATION OF THE LAND.

CLEARING AND LEVELING.

In the coast region some of the best land is still covered with a dense growth of brush, comprising lentisk, jujube, heath, broom, and other characteristic shrubs of the Mediterranean region. This shrubby vegetation is luxuriant in proportion to the depth and fertility of the soil. Its removal generally costs about $16 an acre. In the neighborhood of cities this expense can partly be met by the sale of the wood removed and of charcoal made from it. It costs still more, from $20 to $24 an acre, to clear land which bears a heavy growth of dwarf palm, a deep-rooted plant that still covers extensive areas in Algeria. The roots of the palms can be loosened by means of a steam plow, and then removed with a pick. In the work of clearing land, Spanish, Moroccan, and Kabyle laborers are most expert.

Leveling is done with scrapers, which are generally drawn by horses. The average expense of leveling an acre, if two men and three animals are employed, is about $8.

PLOWING.

The Arab plow, generally used in Algeria, has the forward part supported directly by the yoke or harness of the animal which draws it, while the working part is limited practically to the share. The Kabyle plow consists of two pieces of wood (often the forked branch of a tree) meeting at nearly a right angle, the upright piece being shaped so as to serve as a handle, while to the horizontal piece the iron share is fastened. Two wooden projections at the end of the horizontal piece, just above the share, serve to widen the furrow that is made. The beam is fastened, by means of a peg, into the angle made by the two pieces. One end of the beam is fastened by a strap directly to the wooden yoke of the animal which draws the plow. One man works the plow, driving the animal with one hand and holding the handle with the other. The instruments used by the natives break up the soil only to a very small depth. Among the European colonists improved modern plows are now coming into use. On the largest farms steam plows, operated by two 16-horsepower engines, are sometimes used. In some of the larger towns steam plows can be hired.

For cultivating vineyards, American gang plows are preferred. The use of the disk harrow is widespread.

In preparing for a crop of cereals the land is generally not plowed until fall. This is, however, a bad practice, for if there are heavy rains early in the autumn the land is sometimes too wet to permit of plowing before the first of the year. If, on the contrary, the rains are unusually late, the soil may be too dry and hard to make early plowing possible. In consequence, the crop is sown late and is often dried up by the hot winds of late spring and early summer. Spring plowing in preparation for a winter crop is therefore highly recommended by the best authorities. It is pointed out that as a result of this practice the soil loses less moisture during the summer fallow, besides being in excellent condition to absorb the first rain that falls upon it in the autumn. It is, indeed, advisable to keep the surface of the soil in a well-pulverized condition at all times when there is no crop in the land.

Deep plowing is found to have, up to a certain point, the same effect as rotation and the use of fertilizers. Beyond that point, however, the yield of crops will diminish, no matter how thoroughly the land is plowed, unless some other means is taken to restore the fertility of the soil. At Sétif good cultivation is made to take the place of irrigation, and excellent crops of cereals and of leguminous food and forage plants are produced without artificial watering.

In preparing land that is comparatively flat, in order to establish market gardens, vineyards, and orchards, it has been found that a steam plow, turning the soil to a depth of from 20 to 24 inches, can be used to advantage. In lieu of this an ordinary plow, followed by a subsoiler, will answer the purpose. On hillsides that are too steep for the plow the soil is loosened with picks, usually to a depth of from 24 to 28 inches. The expense of preparing an acre in this way averages about $50. Sometimes the pick is also used for loosening the soil in orchards where the trees are set very close together and in market gardens. The plow used in market gardens is generally a very light one.

GENERAL ECONOMIC CONDITIONS.

HISTORICAL AND POLITICAL.

According to the census of 1896, the population of Algeria, excluding the army, was 4,360,000, of which 86 per cent was Mohammedan. The great importance of agriculture is shown by the fact that four-fifths of the inhabitants live by farming or by raising animals, almost the whole of the native population being thus employed. The total area now under French dominion is about 150,000 square miles, but a large proportion of this area is a barren desert, without water for irrigation. An area of 3,460,000 acres, including most of the best arable land, is held by European colonists, while about 17,290,000 acres is still the property of natives. The remainder, including large forested areas and vast tracts of steppe covered with alfa grass, is government land. There is one inhabitant to every 17½ acres of land belonging to Europeans, and one inhabitant to every 5 acres held by natives.

California, with an area slightly exceeding that of Algeria (156,000 square miles), has a population of about 1,500,000. The combined populations of Arizona, California, Colorado, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, Washington, and Wyoming about equal that of Algeria. The traveler in Algeria does not, however, get the impression that the colony is well populated. On the contrary, it seems a new country, and capable of far greater agricultural development than has yet been attained.

LAND VALUES.

In a country like Algeria, where climate, soils, and crops, not to speak of means of communication and nearness to large commercial centers, vary so much in different regions, it is extremely difficult to generalize as to the value of the land. Within 20 miles of large towns, where there are good facilities for transportation by road or by railway, the best land is worth from $25 to $70 an acre. In proportion as remoteness from important centers and difficulties of communication increase, the value diminishes to $16 or less.

An acre in vines near Algiers, a region unaffected by phylloxera, is worth from $80 to $230. Orchard and truck land well supplied with artesian water sells for from $80 to $160, and the best market-garden land near Algiers at very much higher prices, sometimes as much as $230. Orange groves in full bearing are worth from $480 to $640 per acre. Olive orchards, in land of good quality but not capable of irrigation, range in value from $80 to $240 per acre. An acre of fig trees is valued at $115 to $230. Facilities for irrigation, of course, enhance these values.

FARM LABOR.

The great bulk of the farm work in Algeria is done by the native population—Arabs and Kabyles—either in the employ of European colonists or working for themselves on land they own or rent. The Kabyles, among whom the native agriculture of Algeria has reached its highest development, are generally more industrious and more skillful laborers than the Arabs.

Particularly in the littoral zone of the coast region, where the European population is densest, much of the labor in vineyards, orchards, and market gardens is performed by immigrants from southern France, Spain, Italy, the Balearic Islands, and Malta. In all those countries agricultural conditions resemble to a greater or less extent those prevailing along the African shore of the Mediterranean.

The wages paid native laborers vary according to the locality, the season, and the nature of the crop grown. Wages to natives are highest along the coast, where a day's labor in summer commands from 28 to 38 cents. Farther inland the wage varies between 24 and 28 cents. Harvest labor performed in the usual fashion, with a sickle, is paid at the rate of about 45 cents a day. When the scythe is used from 65 to 75 cents a day is earned. Laborers are sometimes employed by the month, receiving, without board, $6.50 to $7.50. If somewhat more skilled than the average they are paid as much as $9.50 a month, or a smaller wage is given, together with a ration of about 2 pounds of bread daily, and each month 2 quarts of olive oil and a few pounds of dried figs and semolina. For tending small flocks owned by Europeans the native receives from $1.50 to $2.75 per month with food, or $2.75 to $4.75 without food. The employer always retains half of the wage agreed upon until the expiration of his contract with the shepherd, as security for the proper care of his flock. Men whose families live in the neighborhood are found to be the most trustworthy laborers among the natives.

European workmen are more intelligent and consequently better paid than natives. Their wages are higher in eastern Algeria and in the interior, where the conditions are less attractive to Europeans than in western Algeria. The heavier kinds of farm labor, if done by immigrants, fall to the share of Spaniards and Italians. French laborers are generally engaged in such work about the orchards and vineyards as requires more intelligence, and as overseers and foremen. The market gardens of the littoral zone, where large quantities of vegetables are grown not only for consumption in Algeria but for export to Europe, are rented and farmed for the most part by Mahonnais (natives of the Balearic Islands) and by Maltese.

Unskilled Spanish and Italian laborers, working by the day and finding their own provisions, earn from 45 to 55 cents a day in winter and as much as 75 cents a day in summer. The day's work in winter lasts nine or ten hours, with an hour's rest at noon. In summer the workday is twelve or thirteen hours, but with two hours' intermission at noon and a quarter of an hour for rest in the middle of the morning and again in the middle of the afternoon. The same kind of labor, if employed by the month, commands from $5.50 to $11.50, board included. The more intelligent French laborers naturally receive much higher wages.

AGRICULTURE OF THE NATIVE POPULATION.

AMONG THE ARABS.

The Arab, as a rule, is lazy and shows little skill and initiative in his farming. He works only to keep from starving, his ambition being satisfied as soon as he has enough to keep body and soul together. The Arabs of the coast region are chiefly tillers of the soil, living in rude huts or "gourbis," while those of the high plateau and desert regions are for the most part nomadic shepherds, dwelling in tents; but both pursuits—agriculture and stock raising—are often combined in the same family.

Agriculture, as practiced by the Arab who has not been influenced by European methods, is of the simplest description. His plow is made with a few strokes of a hatchet from the branch of a tree, and usually has no metal about it. Hitching to this rude instrument a horse, a camel, or, perchance, his wife, he merely scratches the soil in the autumn and scatters his wheat or barley seed. He then goes over the field a second time with a plow, covering the grain to a depth of 3 or 4 inches. After that is done he folds his hands and waits for the crop which may or may not come, satisfied that he can do no more and that the result is in the hands of Allah. In the spring, before the ground has dried out, he puts in sorghum or Indian corn in a similar fashion. The yields of grain thus obtained are naturally scanty at best, while in dry years the crops sometimes fail entirely and there is much suffering among the Arab population.

In better soils, especially where a little water can be had without much labor, beans, chick-peas, and melons are grown. Near streams the Arab often has a small orchard of figs, pomegranates, oranges, and apricots, or a vegetable garden. None of these crops receive any particular attention, and the yield and quality of the product are generally far inferior to those obtained by skillful European farmers.

AMONG THE KABYLES.

The Kabyles belong to the ancient Berber race that inhabited northern Africa before it was conquered by the Arabs—before even the Carthaginians and the Romans occupied the country. Nowadays they are confined chiefly to the mountainous districts. Their principal territory is the region known as Great Kabylia, lying between the Djurdjura range of mountains and the sea. Here a dense population is crowded into a comparatively small area, much of which is so mountainous and rugged that even these dauntless farmers can not make crops grow upon it. Since the French occupation of Algeria, however, large numbers of Kabyles have left their mountain fastnesses, seeking work as farm laborers in the valleys and plains, or as porters in cities.

Many of these emigrants, however, spend only a part of the year in the lowlands, returning home with their savings and putting in the rest of their time cultivating their own land. Unlike the Arab, the Kabyle is a patient and persistent workman. He is a true mountaineer—frugal, temperate, and hardy.

It is astonishing with how little the Kabyle can sustain life. He often inherits the merest patch of land, or only a single tree—sometimes only a branch of an olive tree that has its roots in another man's land. With this slender patrimony and what he can make by hiring his labor to others, he supports himself and his family. Now that Kabylia is thoroughly pacified and the tribal wars that formerly waged between almost every two neighboring villages have ceased, there is a much larger acreage available for cultivation than was formerly the case. Every inch of arable land is put into crops. Grain and forage plants are grown in the river valleys and lower slopes, figs and olives on the steeper hillsides.

It is in horticulture, especially, that the Kabyles excel, the country they inhabit being better adapted to orchard than to field crops. They are expert in grafting and other horticultural processes. Olive culture is a specialty of these mountaineers. Every year they graft large numbers of scions of improved varieties upon wild trees, and thus constantly extend the area of their olive orchards. Fig trees are also planted yearly in large numbers. They are handled with great skill, caprification being carefully attended to. Of olive and fig trees, as well as of grapes and other kinds of fruit, there are a number of varieties that are more or less peculiar to Kabylia. The dried leaves of the fig and the twigs of the olive that are removed in pruning, as well as the leaves of the ash and the elm, are utilized by the Kabyles as forage for their domestic animals. It is said that two-thirds of the population of these mountains depend absolutely upon the olive and the fig for subsistence. Where these trees are present there are three or four inhabitants to every 5 acres, while in parts of Kabylia where they are wanting, from 5 to 7 acres of land are required to support each person.

The Kabyles do not raise cereals in quantity sufficient to supply their own wants, and they must draw upon other parts of the colony for grain. Flour is made into semolina or baked in an earthenware tray into a sort of unleavened bread. Flour made from beans, nuts, Indian corn, and sorghum is mixed by the poorer classes with barley flour. Often wheat, barley, beans, and other plants are grown together in the same field. Fruits, excepting olives, figs, and grapes, are generally of poor quality, although apricots, pomegranates, peaches, pears, apples, and, in some sheltered valleys, oranges are grown.

Wheat, barley, and beans are sown in the autumn, sorghum and Indian corn in the spring. Otherwise, all these crops are handled in about the same way. Plowing is done with oxen, hitched to a rude, homemade plow of very ancient pattern, which turns up the soil to a depth of about 5 inches. The yoke is so adjusted that the steepest slopes and even the soil about the roots of a tree can be plowed. A man follows the plow, breaking up the clods with a pick. Sowing is done by hand. The fields are kept very clean, the weeds that are removed being used as forage. Harvesting is done with the sickle or even by hand. Grain is thrashed by treading out beneath the hoofs of oxen on a floor of hardened clay. It is winnowed by tossing into the air, the wind carrying away the chaff.

The valley lands are irrigated from the numerous streams that run bank full in the spring. The tiny garden, which every fairly well-to-do Kabyle possesses, is watered and manured with great care, and different vegetables follow one another in constant succession throughout the year. A plot of ground 40 by 80 feet is thus made to produce all the vegetables needed by a large family.

Owing to the small area of land in the mountains that can be spared for forage crops, the Kabyles purchase in the lowlands most of the animals they use in their farm work, fattening and reselling them when the spring plowing is over. Donkeys are generally used for carrying loads, and mules for riding. The Kabyle, unlike the Arab, takes the greatest care of his animals, stabling them at night in his own house and doing his best at all seasons to provide them with sufficient food.

AMONG THE SAHARANS.

The population of the oases in the eastern part of the Algerian Sahara, the only part of the desert that is of much agricultural interest, is of mixed origin. It combines strains of Berber, Sudanese, and Arab blood. In winter great numbers of nomadic Arabs descend into the Sahara with their flocks and herds, which range during the summer over the plains of the high plateau region. But there is also a resident population, which subsists entirely upon the products of the date palm and the various cultures that are grown in its shade. These, the true Saharans, are very skillful gardeners, understanding thoroughly the highly specialized culture of the date palm. They are adepts in the management of soils and irrigating waters that contain excessive amounts of salt. Despite these disadvantages, which are combined with the most unfavorable climatic conditions, they succeed in growing in the oases a variety of fruit trees, garden vegetables, forage plants, and cereals. Not only in their own gardens, but in the plantations of palms recently established by French capital, the labor is performed entirely by natives. The climatic conditions, together with the large quantity of more or less stagnant water that is always present, make the oasis environment, at least in summer, entirely unfit for European labor. Indeed, the Arabs of the coast and high plateau regions are hardly better inured to the summer conditions, which only the thoroughly acclimated natives of the Sahara can endure without suffering.

CROPS OF THE COLONY.

The greatest wealth-producing crop of Algeria is the vine. The climate and soils of a great part of Algeria, as of California, are perfectly adapted to viticulture. The French colonists have put by far the greater share of their energy and capital into the growing of wine grapes. In 1898 the average annual value of the product of Algerian vineyards was estimated at $5,000,000. The red and the white table wines of the colony are steadily improving in quality and are coming more and more into favor among foreign consumers. There is also a considerable production of early table grapes for the markets of Europe.

Various orchard crops are likewise a source of revenue. First and foremost stands the olive. Algeria is extending year by year the area planted to olives, a product for which northern Africa has always been famous. As the inability of Italy and Spain to supply the world's demand becomes more and more evident, the export of olive oil from Algeria and Tunis will doubtless steadily increase. Citrus fruits, particularly mandarin and other oranges, are exported in considerable quantities. In this industry, however, Algeria finds herself in competition with Spain, Sicily, and other countries which have the advantage of a larger or at least a better distributed rainfall. Figs are grown in most parts of the colony. In Kabylia they are dried and prepared for export, although the finest sorts of figs for drying are not grown in Algeria.

A considerable variety of other fruits is grown, chiefly for domestic consumption, among which may be mentioned pomegranates, apricots, almonds, peaches, cherries, plums, apples, and pears. Tropical fruits, such as the banana, pineapple, guava, and avocado, can be produced in the open only in a very few localities along the coast, and can never become crops of the first rank. The kaki and the loquat are more promising.

A restricted yet important industry in Algeria is the production of dates. Especially in the Sahara, dates form a staple food of the inhabitants, who eat great quantities of the ordinary sorts. The finer varieties are now being grown in some quantity for export to Europe, and a considerable amount of French capital has been invested in this enterprise.

Market gardens occupy a considerable area near the sea. Large quantities of vegetables are grown, not only for the use of the home population but for shipment to Europe to supply the winter and early spring markets. Of those which are exported, artichokes, potatoes, beans, and peas are the most important. The consumption of melons and watermelons in Algeria is very large during the summer.

The principal field crops of the colony are cereals. Wheat and barley occupy about 7,000,000 acres annually and supply a large export trade. Indian corn and sorghum are extensively grown by the natives. Cotton and sugar cane, crops to which Egypt owes so much of her wealth, are of small importance in Algeria. The only valuable "industrial" crops are tobacco and certain plants used in the manufacture of perfumery. The cork oak and the grass known as alfa, which contribute largely to the prosperity of the colony, are never artificially planted and hence are not, strictly speaking, agricultural products.

The acreage in forage crops is limited, particularly in summer, by the scanty water supply. Alfalfa is grown generally in small patches, although on the larger estates good-sized fields are sometimes put into this crop. Sulla has been frequently recommended but has not come into general use. The pods of the carob tree, or St. John's bread, are used for feeding stock. They are consumed in considerable quantities in the colony and are also exported. Sorghum is also grown extensively and affords a valuable supply of summer forage. In the autumn, in some localities, vetches are sown with oats or barley and are harvested in the spring. This mixture, either green or cured, is an excellent food for cattle. Oats are grown for export only, barley being the grain commonly fed to horses.

The greater number of the cattle and sheep of Algeria are raised upon the wild forage which covers the uncleared portion of the hills and plains or springs up in the cultivated fields after the crop of grain has been taken off. The supply of green pasturage is abundant during the winter and spring, but the hot, dry summer soon burns it dry. As cultivated forage is scarce in summer animals often have great difficulty in obtaining feed at that season.

GEOGRAPHICAL DISTRIBUTION.

COAST REGION.

The great diversity which the coast region exhibits in respect to climate, topography, and soils is paralleled by the great diversity of its agricultural conditions. A far greater variety of crops is grown there than in either of the other regions. The three zones—littoral, valley and plain, and mountain—are distinguished one from another by agricultural as well as by topographical and climatic peculiarities, so that it will be advisable to give a sketch of each in turn. Roughly speaking, the first is a zone of orchards and market gardens, the second of grain fields and vineyards, and the third of tree crops at lower elevations, giving place to pasturage on the higher slopes and crests of the mountains. But this generalization must not be carried too far. The lines that separate the three zones are vague at best, and the industries especially characteristic of each are shared to some extent by all.

LITTORAL ZONE.

Along the shore of the Mediterranean is practiced the most intensive agriculture of the colony, if we except the oases of the eastern Sahara. The alluvial soils of the valleys, which usually expand into small deltas as they approach the sea, are largely occupied, especially in the neighborhood of the principal cities, by highly cultivated market gardens. The lower slopes of the hills and mountains that border the sea are occupied by orchards and vineyards. At slight elevations we find a great variety of fruits, every sort, in fact, that is commonly grown in warm temperate countries. In addition to the great vineyards of wine grapes, excellent table grapes are grown for European as well as for Algerian markets. Oranges of several kinds are produced in considerable quantity. Lemons, apricots, nectarines, and almonds thrive. The Japanese persimmon, the loquat, the pecan, and other tree crops not yet widely cultivated in that part of the world, promise to become a source of wealth. A few peculiarly favored situations, well sheltered from cold winds in winter and from the sirocco in summer, are adapted to fruits of a distinctly tropical character, such as bananas, guavas, and avocados. Attempts are being made to produce some of these fruits under glass in marketable quantity.

It must not be supposed, however, that the littoral zone is devoted wholly to growing fruits and garden vegetables. Where sufficiently extensive areas of alluvial soil occur, cereals are grown, giving larger yields than elsewhere because of the abundant supply of water. For the same reason cultivated forage plants do better in this zone than in the others. Alfalfa is the most important perennial forage crop, while, for winter forage, barley, often sown with vetches, is much used. As is also the case to some extent in the other zones of the coast region, natural meadows, furnishing green pasturage all the year round, occupy marshy places. Where such meadows occur, live stock can be kept in good condition throughout the summer, which is seldom possible in the high plateau region.

An industry of secondary importance, yet bringing a considerable yearly revenue into the colony, is that of growing plants used in the manufacture of perfumery, notably the rose geranium.

VALLEY AND PLAIN ZONE.

The large valleys of the coast region, especially in the western part of the colony, of which the Chéliff may be taken as a type, are given up in great part to grain production. Of the 12,500,000 acres in Algeria which bear a cereal crop every one or two years, by far the largest part is situated in this zone. Wheat, barley, and oats are grown, the last in much smaller quantity than the others and solely for export. The bulk of the wheat is of the hard or durum type, although soft wheats are also produced.

Where water for irrigation is to be had in summer—and this is the case in only a small fraction of the whole area—alfalfa, sorghum, and other forage plants, as well as tobacco, melons, etc., are grown. Cotton was extensively planted in some of the valleys of western Algeria during the civil war in the United States, and proved very remunerative for a while. Under present market conditions, however, it can not be grown with profit in the colony.

The wild forage that springs up on the extensive areas of grain land lying fallow every year is an important resource to the farmer, enabling him to keep his cattle in good condition during the winter. In summer, however, unless a forage crop is grown under irrigation, the conditions for animals in this zone are unfavorable.

MOUNTAIN ZONE.

The only extensive district of high mountains in Algeria where agriculture is highly developed is Kabylia. In discussing the agriculture of the "mountain zone" we are therefore, as a matter of fact, describing that district.

The lower elevations and the valleys of the larger streams present conditions not unlike those of the littoral zone. Even oranges can be grown in sheltered situations at low altitudes. On the higher slopes and the crests of the ridges, however, this is impossible. The nature of the surface is not adapted to large vineyards and grain fields; hence, agriculture becomes reduced to horticulture. Orchards of figs and olives cover the middle elevations, often on the steepest hillsides. Olive oil is produced in large quantities in the eastern part of this mountain region. It is extensively used by the inhabitants and is also an important article of export from Bougie, the principal seaport of the district. Other agricultural products of the mountain region which contribute to the export trade of the colony are dried figs, the pods of the carob, or St. John's bread, and capers. The last are not cultivated, but are gathered by women and children from the wild plants, the young flower buds being the part used in commerce. About 450,000 pounds of capers were exported in 1899. The mountaineers raise in small gardens such cereals, vegetables, and forage plants as they require for their own use. These gardens are generally situated at the bottoms of valleys and ravines, where some alluvial soil has collected.

The highest elevations of the mountain zone are not suitable for any sort of agriculture, but are largely covered with grass, which affords abundant pasturage to flocks of sheep and goats.

HIGH PLATEAU REGION.

In the typical steppe region of central Algeria agriculture is limited to occasional low places where, by means of the natural moisture of the ground or by irrigation with the water of a well, a crop of barley can be made in winter. If conditions are exceptionally favorable, a small garden can sometimes be established. At such points as Sétif and Batna, in the eastern part of the colony, there are extensive areas in winter cereals, where crops are produced without irrigation. But, as we have already seen, these places are not to be regarded as typical of the high plateau region. Agriculturally, they belong rather to the valley and plain zone of the coast region.

The two great industries of the high plateau region are grazing and the collection of alfa. Vast numbers of sheep and goats, as well as horses and camels, are pastured, especially in summer, on these elevated grassy plains. It is estimated that from 6 to 10 million head of sheep and 3,500,000 goats range the high plateau. These animals are almost without exception the property of Arabs. Many of them are wintered in the Sahara, and in spring are driven by their owners up to the high plateau, where pasturage is more abundant and the heat less intense. The hides, meat, wool, and other products of these animals are a very material source of wealth to the colony. Cattle are not raised in any considerable number.

Alfa, or esparto, covers vast areas of this region, often to the almost complete exclusion of other vegetation. The tough leaves of this grass form one of the most valuable exports of the colony, amounting annually to about $2,000,000. They are used in the manufacture of high grades of paper, basket ware, matting, hats, and cordage. The harvest takes place in the spring. Persistent exploitation is resulting in the rapid extermination of alfa grass, the more so because attempts to establish artificial plantations have so far been wholly unsuccessful.

DESERT REGION.

The oases of the Sahara, and particularly those of the depression known as the Oued Rirh, in the eastern part, are the only portion of the desert that is of much agricultural importance. There the presence of subterranean streams, carrying a considerable volume of water, has made it possible to plant thousands of date palms in groves of greater or less size.

Within the last three decades the sinking of a number of artesian wells in the Oued Rirh region has much increased the supply of water for irrigating purposes. Consequently, it has been possible to create new oases and to extend greatly the area in date palms. Two French companies have set out many thousands of palms of the best varieties, especially the celebrated Deglet Noor, and have introduced improved methods of cultivation and management. Dates have always been an important article of export from the Sahara to other parts of Africa. Recently a large export trade with Europe has been developed.

A considerable variety of fruits, vegetables, cereals, and forage crops is grown among the date palms in the oases. These, however, do not afford products for export to foreign countries, but serve merely to supply the wants of the local population. The area available is too small to allow these subordinate cultures to attain any considerable magnitude, even cereals and forage plants being grown in gardens rather than in fields.

Oranges are grown in the oases at the foot of the mountains that border the desert, but do not succeed farther south because of the occasionally severe winter frosts. Olives for oil and the large sorts used for pickling, almonds, several kinds of figs and grapes, pomegranates, apricots, and other fruits are produced. The apricots grown are of a native type and are remarkable for the large size the trees sometimes attain. The different kinds of fruit trees are not set out in separate orchards, but are mingled together. The same system, or lack of system, is observed in the way garden vegetables are grown. Of these the more common are onions, broad beans, carrots, cabbage, tomatoes, okra, eggplant, pumpkins, cucumbers, melons, and peppers. Alfalfa is grown in small, carefully tended patches, and is cut many times during the year. The cereals chiefly grown are wheat and barley in winter, and sorghum and Indian corn in summer. On the northern edge of the Sahara, where the slope is considerable and occasional heavy rains in winter cause a sheet of flood water to sweep down over the land, this is taken advantage of in producing crops of grain in the open desert bordering the oases. Ridges of mud are thrown up at intervals, and are arranged so as to catch and retain for a while the flood water.

PRINCIPAL CROPS IN DETAIL.

FRUIT CROPS.

GRAPES.

Wine grapes.—Grapes have long been an important product of Algeria, for even before the French occupation about fifty varieties were known to the natives. In Kabylia particularly, well-defined local varieties had been developed. Some of these are grown only in that country, apparently, while others occur under different names in other parts of the Mediterranean region. Until within the last three decades, grapes were grown chiefly for eating purposes, as the Mohammedan law forbids the use of wine. Since then, however, the planting of vineyards has made rapid progress among the colonists, and in 1900 nearly 350,000 acres, about one-tenth of the land owned by Europeans, was in vines. The estimated total value of Algerian vineyards is $114,000,000. Wine is now the most valuable product of the colony, the export amounting in 1899 to over 120,000,000 gallons. Most of the skill, energy, and capital of the French population is concentrated upon this crop. It has been computed that $6,650,000 is paid out annually in wages to the laborers in Algerian vineyards.

Fine wines and dessert wines form but a small part of the total yield, the Algerian product consisting chiefly of heavy-bodied and, in the case of red wines, deeply colored wines for blending purposes. These are being constantly improved in quality, and Algerian wines are now widely and favorably known in Europe—France, England, and Germany, especially, importing large quantities.

The varieties of wine grapes chiefly grown by European colonists are those of southern France. Carignane, from which red wine is made, is at present the favorite, and is being planted more extensively than any other variety. Other highly esteemed varieties that furnish red wine are Mourvèdre, Morastel, Aramon, Cinsault, and Ulliade (Oeillade). Carignane is notable for the rapidity with which it comes into bearing and for its large yields. At the same time it requires more care than some other varieties, and is subject to fungous diseases. Mourvèdre and Morastel, hardier varieties, but slower in developing and somewhat irregular in yield, are not as extensively planted as formerly. Cinsault and Ulliade are hardy varieties, and endure the trying conditions that prevail when the sirocco is blowing. The former, especially, is much grown. The latter is said to be very irregular in its yields. The variety known as "Petit Bouschet" is used for giving a deeper color to certain French wines made from other varieties.

White wines are made from the Clairette, Ugni Blanc, Semillon, and other varieties, while a native variety known as Feranah is highly esteemed by some vineyardists. All these, however, give rather light yields, so that the making of white wines from grapes having a colorless juice is now much practiced, the skins being removed before fermentation begins. Cinsault, Aramon, and Mourvèdre are especially used for this purpose. Excellent dessert wines are occasionally made from such varieties as Alicante and Muscat.

Vines are grown in nearly all parts of the colony, even in the extremely mountainous districts and in the oases of the Sahara; but the most extensive vineyards have been established in the great plains and valleys of the coast region, where the largest profits from the growing of wine grapes have been realized. Deep alluvial soils, containing a considerable amount of clay and of organic matter, are found to give the largest yields. These soils retain enough moisture during the summer to prevent much harm to the vines from the sirocco. The better qualities of wine are, however, commonly produced on hillside vineyards, at altitudes not exceeding 3,000 feet. Some districts that are otherwise perfectly adapted to vineyards suffer so heavily from hailstorms in spring as to make them unprofitable for grape culture.

The vines are planted to best advantage in squares or in a quincunx, i. e., in squares with one vine at each corner and one in the center. It is very important to arrange the vines so that the vineyard can be plowed in both directions. It is considered advisable, under Algerian conditions, when planting in squares, to set the vines 5, or, for some varieties, 6 feet apart each way. The vines are set out during the months of January, February, and March. Pruning is generally done in the latter part of the winter. The varieties most commonly grown by the colonists, such as Carignane, are trimmed back close to the stump, leaving a circle of 5 to 8 spurs. When trimmed long, the canes are trained on wire or are supported by forked sticks. Among the Kabyles, the vines are generally allowed to grow on trees. Close trimming is said to increase the ability of the vines to resist drought, which is an important matter in Algeria. Grafting is resorted to when it is desired to replace the varieties in a vineyard with better varieties, and to render it more productive, March and April being the best months for this operation. In Algeria vines generally begin to bear in their fourth year, although a full crop is not obtained until the sixth or seventh year.

Late in the winter, after trimming is completed and before the buds have begun to start, the vineyards are plowed, usually to a depth of 6 inches. This should be done when the soil is fairly dry. Occasionally the plow is followed by a subsoiler. Vines send their roots deep into the soil in Algeria, so that there is little danger of injuring them by this treatment. A hoe or pick is used to loosen the soil around the roots of the vines. In some vineyards, in order to cover the roots, a cross plowing is then given which, like all subsequent plowings, is shallower than the first. During the summer the vineyard is given as many cultivations with the hoe or the scarifier as are necessary to rid it of weeds and to preserve a loose mulch on the surface of the soil that will keep down evaporation. Bermuda grass is often a serious pest in Algerian vineyards.

Although in vineyards careful cultivation will partly take the place of irrigation, the yield can almost always be increased by the judicious application of water. Irrigation in winter, so as to store up water in the soil, is recommended for such regions as the Chéliff Valley, where the rainfall is small. The first irrigation in summer generally takes place when the grapes begin to color, and the second about two weeks before the vintage. About 2 acre-inches of water is used in flood irrigation, but only about 1½ acre-inches in furrow irrigation. It is desirable to follow each irrigation by a cultivation, in order to keep down weeds and prevent the surface of the soil from baking.

Nitrogenous fertilizers are needed in maintaining the wood growth of Algerian vineyards, and phosphoric acid is also often required to promote productiveness. Farm manure is much used and is applied at the rate of 12 to 18 tons per acre.

When wine making first began in the colony great difficulty was experienced in completing fermentation, and the quality of the wine was much impaired by the presence of unfermented sugar. This was due to the high sugar content of the Algerian grapes and to the high temperatures prevailing during fermentation. These difficulties have been largely overcome, however, by observing certain precautions. If the weather during the vintage is very hot, the grapes are gathered and put into the vats in the early morning while they are cool, and the temperature of the vats is kept down by causing cool water to circulate on the outside of them.

The fungous diseases, such as anthracnose, oïdium, and mildew, which attack vines in Algeria, have been more or less successfully kept in check by spraying. Not so, however, with phylloxera, which has wrought terrible havoc in the vineyards of Oran and Constantine departments since its first appearance in the colony in 1883. A very rigid inspection law has failed to put a complete stop to its ravages. The practice of flooding infected vineyards, which has given such happy results in southern France, can not be generally adopted in Algeria because of the scarcity of irrigating water. So far the vineyards of the central department, that of Algiers, have escaped damage from this destructive insect.

In the vineyards of western Algeria considerable losses have been sustained through the rise of salts in the soil. The effect of salt in the soil upon Algerian vineyards has been discussed by Dugast (see p. 44 of this report), who calls attention to the existence of occasional more resistant plants. In some districts the vines have been killed, while in less extreme cases the quality of the wine has been much impaired by taking up more or less of the salt contained in the soil. A French law forbids the sale of wine containing more than one part per thousand of sodium chlorid, but in some of the wine produced in Oran Department this percentage has been exceeded. It is considered safe to plant vines in any soil that is not too salty to permit a good growth of figs, pomegranates, alfalfa, or artichokes.

Table grapes. Excellent table grapes are grown, some of which—the Cinsault, for example—are valuable also as wine grapes, while others, like the Golden Chasselas, are grown chiefly for the table. The latter is by far the most popular variety. It is an excellent grape, bearing shipment well. Grapes mature early enough for profitable exportation in the littoral zone of the coast region only. Near Algiers the Chasselas ripens in the first part of July and reaches the French markets in advance of home-grown grapes. Vines of this variety generally begin to yield freely in their fifth year. Reeds are usually planted as a wind-break, the same as in market gardens. An average crop from an acre is 3 tons of fruit. The first Algerian grapes that reach the Paris markets are said to bring as much as $26 per 100 pounds.

Table grapes grown elsewhere than along the coast ripen too late for export, but often find a good sale in local markets. The varieties peculiar to the colony are generally of inferior quality, although some of them are not without value. Those grown in Kabylia are nearly all pruned to long canes, and often ascend to the tops of tall trees. It is difficult to gather the grapes from such vines or to spray them when infected with fungous diseases.

Raisins are dried in small quantities by the Kabyles. Otherwise this industry has not developed in Algeria, although the climatic conditions would seem to be peculiarly favorable to raisin making.

OLIVES.

From the earliest times of which we have record the olive has been one of the most important products of northern Africa. The same varieties yield a higher percentage of oil in Algeria and Tunis than in southern Europe. The oil content varies greatly in different parts of the colony, but as high as 34 per cent has been obtained from olives grown in the oases of the Sahara. African oils have a higher margarin content and are more easily fixed at a temperature of 40° F. than oil made from European olives. The annual production of oil in Algeria is estimated at 13,200,000 gallons, the bulk of which is consumed in the colony. The export trade is as yet comparatively insignificant, amounting annually to only about $200,000. In fact, Algeria does not produce enough for home consumption, importing annually from 2,500,000 to 3,000,000 gallons of edible oils. The number of grafted olive trees in the colony is estimated at 4,500,000, the greater part of them being in Kabylia. Tunis, the olive-growing country par excellence of northern Africa, is said to contain some 15,000,000 grafted trees, covering about 500,000 acres. The olive is thoroughly at home in Algeria, especially in the Kabyle mountain district, where several local varieties exist, some of which are of considerable value.

Like some of the vines, some of the olive varieties are found only in the colony, while others, which have received local names in Algeria, are widely distributed in Mediterranean countries.

The olive grows wild in almost every part of Algeria, here and there forming actual forests, some of which were formerly of much greater extent than they are to-day. The fruits of these wild trees are worthless, but the stocks are much used for grafting with improved varieties. In Kabylia especially, the area in olive orchards is being rapidly extended by grafting wild trees.

The olive flourishes in a great variety of soils and is less sensitive than citrus fruits to cold and drought. Yet it has limitations, which must be considered when a new orchard is to be established. Well-drained soils, having a considerable slope, give the best results. The maximum oil production is said to be obtained from soils rich in lime. Sunny situations are to be preferred, although in districts subject to frosts in spring it is desirable that the trees should not be in a position where the first rays of the sun can strike them in the morning. A paying crop can not be expected in districts where temperatures as low as 25° F. or exceeding 105° F. are frequent.

In respect to elevation, olives will not thrive in Algeria at an altitude of much more than 3,000 feet, and appear to do best between 1,000 and 2,000 feet above sea level. In the immediate neighborhood of the sea the orchards suffer most from the ravages of certain insect enemies and of a bacterial disease. Olive orchards are particularly profitable in districts like the Chéliff Valley, where they can be irrigated three or four times during the winter. If irrigation in summer is also possible, the yield can often be doubled. At each watering, from 1.5 to 2 acre-feet is applied.

Where an orchard is to be started with young trees, these are set out in most parts of Algeria to best advantage at intervals of 30 feet, in rows 50 feet apart. Sometimes the quincunx plan is adopted. On irrigated land, about 40 trees to the acre is the proper number. Planting is done during the winter, preferably in December or January. After six or eight years an orchard started with trees 5 feet high and 2 or 3 inches in diameter will generally pay expenses, and in fifteen years it will be in full bearing.

Other cultures are not permitted in the orchard, unless the water supply is ample and the soil is either naturally very fertile or is well manured. Cereals are often grown among the trees, but this tends to diminish the yield of fruit, and is generally discontinued after the trees begin to bear. On the other hand, where water is plentiful, the growing of broad beans and similar leguminous crops in olive orchards is a good practice.

Fertilizers, applied in alternate years when the trees are not bearing, largely increase the yields. A good tree, if furnished about 500 pounds of farm manure every other year, will yield 550 to 650 pounds of fruit every two years. The average yield from a tree 20 years old appears to be about 175 pounds, from 12 to 15 per cent of the weight being oil. The best method of keeping the soil of an olive orchard in first-class condition is to give it a good plowing as soon as the harvest is over. During the summer two or three cultivations are given, in order to keep the surface well mulched and thus reduce evaporation. The harvest begins in October, green olives, for pickling, being the first that are gathered.

By far the greater part of the oil crop of the colony is obtained from fruit grown by the natives, who themselves manufacture two-thirds of the oil produced and also supply with fruit the oil mills that are operated by Europeans. European colonists have not, so far, devoted as much attention to olive growing as the importance of the crop would warrant. In western Algeria, however, in districts infected with phylloxera, olives are often planted in vineyards, so as to take the place of the vines in case the latter should be destroyed.

Olive growing is the principal industry of Kabylia. Very little care is there given to the cultivation of orchards, this being generally limited to a single plowing in spring. The furrows are run horizontally along the hillside, so that as much rain water as possible can be retained in the soil. The trees are pruned with a hatchet while the fruit is being gathered. The whole family—men, women, and children—take part in the harvest, which is a sort of festival, like the vintage in European countries. Hired pickers are paid with a certain proportion of the fruit they gather. A woman can earn, during the two months of the picking season, olives enough to yield about 15 gallons of oil, worth perhaps $6.

Europeans who manufacture olive oil purchase the fresh fruit from native growers, paying from 40 cents to $1 per 100 pounds. The fruit is brought to the mills in baskets made of reeds or of olive twigs. In every Kabyle village there is a small oil mill, the miller being paid for his work with the product of the second pressing. The strong flavor of the oil made by the natives, which is very unpalatable to Europeans, is due to the fact that the fruit is not pressed while fresh, but is spread out for several months after gathering on a surface of hardened clay, where it is exposed to the sun and weather. The Kabyles use oil almost wholly in place of butter and lard, frying food in it and eating it on bread and "couscous."

Olives for pickling are grown in Algeria only in a small way, generally in the gardens of natives.

FIGS.

The fig ranks next to the olive in importance among the orchard crops of Algeria. Like the olive, it is most extensively grown in the mountain zone of the coast region, although common in every part of the colony. In Kabylia no less than two dozen varieties, some of them of excellent quality, are known. Figs, both fresh and dried, form a large part of the food of the Kabyles, who also export to Europe a considerable quantity of the dried product. The finest varieties for drying, such as are grown near Smyrna, are not, however, grown in Algeria, except in an experimental way. Figs are cultivated in the shade of date palms in the oases of the Sahara; but neither in yield nor in quality do the desert-grown figs compare with those of the mountains. Fig trees do not endure well the severe climate of the high plateau.

In the larger valleys of the coast region heavy yields can be obtained under irrigation. Some varieties grown in Algeria bear two crops a year; others, only one. In establishing a fig orchard, either nursery stock, budded from 2-year-old wood, or root shoots from good trees are used. Budding is generally done in February or March. Growth is rapid, amounting often to 5 feet during the first summer. The trees, when old enough for the orchard, are set out in winter, generally about 30 feet apart. The only pruning done consists in removing the dead wood and the shoots at the base of the trunk. The orchard is occasionally given a shallow plowing or cultivation. In most Algerian soils it is found that fertilizers containing phosphoric acid and potash, if applied in late winter, materially increase the yield of fig orchards.

In Kabylia, where the acreage in figs is constantly being increased, this tree bears well up to an altitude of 4,000 feet. More care is given by the Kabyles to fig than to olive orchards. The trees are sometimes reproduced by cuttings, but preferably by root shoots. Pruning is done during the winter. In January or February the first plowing is given, and is followed by several others during the spring. Several varieties grown in that district require to be caprified. In other words, in order to set fruit, their flowers must receive pollen from those of the wild fig, and this is carried to them by a small insect (Blastophaga) which lays its eggs in the young flower clusters of the wild fig, or caprifig. The first caprification usually takes place in June, and the operation is sometimes repeated three or four times during the summer. The method of the Kabyles is to thread together a few of the "male" figs or caprifigs and hang the chaplets thus made over the branches of the trees, the flowers of which are to be pollinated. Caprifigs sometimes sell for 6 cents a dozen among the natives. In fig orchards managed by Europeans the expense of caprification is estimated at about $5 per hundred trees.

In the mountains the harvest of figs for drying, although at its height in September, covers a period of about three months, as the fruit does not all ripen at once. As fast as the fruit matures it is gathered and placed in shallow trays. These are spread out on the ground when the sun is shining, but are piled together in the evening and placed under shelter when it rains. The fruit is turned over from time to time until it is dry. Figs that are kept for home use or for shipment to other parts of the colony are split down the middle and pressed in a mortar into a compact mass. Those intended for export are packed at the seaports into crates holding 70 or 80 pounds, made of leafstalks of the dwarf palm.

CITRUS FRUITS.

Only a comparatively small portion of the total area of Algeria is suitable for citrus fruits. Even oranges can be grown successfully only in the coast region, up to an elevation of 1,700 feet or thereabouts, and in the northern oases of the eastern part of the Sahara, notably at Biskra. In the oases, however, they are not very satisfactory in yield or quality. The best orange-growing district is that around Blida, in the Mitidja Valley at the base of the Atlas Range. Here has been developed an excellent type of early-ripening, sweet orange, known as the "Blida," the harvesting of which begins in October. The Malta blood orange thrives both in the coast region and in the oases. Brazil, Portugal, Jaffa, and other races are also grown in the colony. The natives grow oranges mostly from seeds, so that the quality of the fruit they produce is generally very inferior; yet some of the native varieties, notably in Kabylia and in the mountain ravines near Blida, are said to possess considerable merit.

The expense of starting an orange grove in Algeria is sometimes lessened by growing truck crops in the young orchard for the first six years. This practice, however, is not recommended by the best authorities. A row of cypress trees is commonly planted as a windbreak around orange groves. The average profit from an acre of oranges is said to be only about $45 annually. The bitter orange (bigarade) is very hardy in the colony and is much used as a stock upon which to graft less resistant varieties. From its flowers perfumery is manufactured.

Mandarins, which are extensively planted in Algeria, generally pay better than ordinary oranges. One authority estimates that an acre of these fruits gives an average net profit of $60 to $90. The harvest of mandarins at Blida begins in November. Lemons are less extensively planted, although they are quite hardy and yield well in the littoral zone.

For the irrigation of citrus fruits in the manner usually practiced in Algeria—by means of shallow basins around the base of each tree—

from 1.5 to 2 acre-inches of water is used at an application. If the soil is very permeable, as is the case in the Blida region, the orchard must be watered every week. Otherwise, an irrigation every two weeks suffices. As to cultivation, a plowing in March to a depth of 1 foot, a second plowing in May, and a cultivation in August are recommended.

DATES.[a]

Except in a single locality, where peculiar conditions exist, the date palm does not ripen its fruit freely in the coast region. Nor is the high plateau, with its cold winters, adapted to this tree. The true home of the palm is the desert region, particularly the low, eastern part. (See Pls. I and III.) In the oases of the Oued Rirh district the finest varieties of dates—notably the celebrated Deglet Noor—reach the acme of their development.

The environment in which the date flourishes is a peculiar one. It can not grow in the dry desert if the ground water is beyond the reach of its roots unless it is copiously irrigated. To ripen the fruit of the best varieties, frequent summer temperatures of 105° to 110° F., together with a very dry atmosphere and a very small rainfall, especially in the autumn, appear to be necessary. It is obvious that this combination of conditions is not to be met with everywhere. The area which possesses the needed climatic requirements is almost limitless, but an abundant supply of water for natural or artificial irrigation is of rare occurrence in the desert.

There are a great number of varieties of the date palm in the oases of Algeria—probably at least 150. These are usually easily distinguished by the character of the fruit, whether long or short, thick or thin, light or dark, with a large or small stone, etc. One of the commonest types is Rhars, an early-ripening soft, sweet date not suitable for exportation, but very popular among the inhabitants of the Sahara. Dates of this kind are either eaten fresh or, pressed into a compact mass, are stored and carried from place to place, usually in leather bags. The Deglet Noor is the date which is most extensively grown for the European trade. Put up in small wooden boxes, with the dates attached to the branch upon which they grew, this fruit bears shipment admirably, retaining without difficulty its shape and firm texture. It is one of the finest of table dates, not only because of its flavor but for the reason that it is clean and easily handled. The fine color and the transparency of the flesh add further to its attractiveness. During the last two decades the two French companies that are engaged in date growing in the Algerian Sahara have set out thousands of Deglet Noor trees. The natives also have planted them in large numbers. Of still another type are the dry dates which furnish a large part of the food of the population of the desert and are transported by caravans to every part of northern Africa. They are not sirupy like the Rhars type nor richly flavored like the Deglet Noor, but are a wholesome food and can be kept for indefinite periods. The best sorts are eaten either fresh or dry, while from the starchy flesh of inferior kinds flour is made and baked into a sort of bread.

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[a] For a full discussion of this interesting subject by Mr. W. T. Swingle, see the Yearbook of the United States Department of Agriculture for 1900, p. 453, and Bulletin No. 53 of the Bureau of Plant Industry, 1904.

In addition to dates, the natives of the Sahara obtain various other useful products from the palms. Trees of inferior value are made to yield "lagmi," or palm wine, a sweet juice which is obtained in abundance by cutting the bud at the summit of the stem. The wood of the palm is used for building houses, bridges, and dams, as well as for fuel. The leaves serve for thatching roofs, while from their fiber matting, baskets, hats, fans, and other articles are manufactured.

LESS IMPORTANT ORCHARD CROPS.

A great variety of other fruits characteristic of warm temperate and subtropical countries are grown with more or less success in Algeria, but their importance is not sufficient to warrant much more than an enumeration.

The peach is most at home in sheltered ravines of the mountain zone, where it makes a rapid growth and yields well. It is grafted upon *Prunus mirobalan* in deep, rich soils, and upon the almond in thinner, limy soils. The fruit is often of fine appearance, but generally lacks flavor.

The apricot is also grown most successfully in ravines and on sheltered slopes at low elevations in the mountain zone. In the oases of the northern part of the Sahara it becomes a large tree and yields heavily, but the fruit is poor in size and quality. Nevertheless, dried apricots are much in demand in the markets of the Sahara. The apricot in the coast region is sometimes grafted on the plum.

The almond is one of the fruit trees that is best adapted to the drier parts of Algeria. Two principal types are cultivated – the thin-shelled Princesse, which is exported in some quantity as an early fruit, and varieties with harder shell, which are generally dried.

The cherry is most at home in the mountain zone, doing well on a variety of soils. There are cherry orchards of considerable value in some parts of Algeria.

The plum thrives in rather deep soils, especially in the mountainous parts of the colony. The Reine Claude gives excellent results under irrigation at moderate elevations in eastern Algeria. The growing of prunes has not become an industry in the colony.

The pear grows vigorously in ravines and on shaded slopes in the mountain zone, especially in deep loamy and clayey soils. There are a number of native varieties of small value. Improved European varieties rarely give satisfactory results.

The apple is even less successful in Algeria, save in a few exceptional localities.

Among fruits characteristic of warmer parts of the world, the pomegranate should be mentioned. It is very hardy as to climate, but needs a moist soil in order to give the best results. Under irrigation good yields can be obtained. A number of types are grown in Algeria, the best sweet fruit being exported and bringing a good price. The better sorts are propagated by cuttings. The spiny, unimproved type of pomegranate is much used as a hedge plant.

The Indian fig, or prickly pear, is abundant in the coast region, where it is almost perfectly naturalized. It also occurs in some of the oases, but the high plateau region is generally too cold for it. There are several different races, some with yellow, some with red fruit. A white-fruited variety, of very limited cultivation, is said to be the finest of all. Indian figs are highly esteemed by the natives and by Spanish and Italian immigrants, but are rarely eaten by the French.

Japanese (kaki) persimmons do well in most parts of the coast region and promise to become one of the important fruit crops of the colony. The loquat is more sensitive to cold, but thrives in the littoral zone. In a few sheltered places along the coast bananas can be successfully grown, the "fig banana" being the type that yields best in Algeria. There is only a small area where the cultivation of such tropical fruits as the guava, avocado, cherimoya, and pineapple is possible.

In the Aurès Mountains walnuts flourish. Plantations of chestnuts, established some years ago by the forestry service, are now bearing abundant crops. The acclimatization of the pecan is being attempted by the botanical service of the colony.

TRUCK CROPS.

A great many garden vegetables are grown in Algeria, among which may be enumerated artichokes, asparagus, beans (broad, kidney, and string), beets, Brussels sprouts, cabbage, cardoon, carrots, cauliflower, celery, chick-peas, chicory, cucumbers, eggplant, garlic, lentils, lettuce, melons, onions, peas, peppers, sorrel, spinach, squash, strawberries, sweet potatoes, tomatoes, turnips, and watermelons. Most of these are grown chiefly for the local markets. In the littoral zone, however, the production in winter of early vegetables for export to Europe is an industry of considerable importance, some 20,000 tons being shipped out of the country every year. Artichokes, potatoes, peas, and string beans are the most important of these. The growing of early tomatoes for export is also becoming a profitable industry.

Near Algiers especially, market gardens abound. There the industry is chiefly in the hands of natives of the Balearic Islands, while in western Algeria the gardeners are generally Spanish, and in the eastern part of the colony Italians and Maltese. Neither the natives nor the French colonists have gone into the business of growing truck crops for export, although Arab and Kabyle families usually have small gardens in which they raise vegetables for their own use.

There are a number of factors which combine to limit gardens as a commercial enterprise to the neighborhood of the seashore. Nowhere else, except in the Sahara, are the winters sufficiently warm to allow Algerian vegetables to be put upon the markets of Europe early enough to insure a remunerative price. As it is, the competition of the Riviera, and other parts of the northern shore of the Mediterranean, has in recent years cut down by 40 or 50 per cent the prices formerly obtained. Facilities for rapid transportation by water, such as are obtainable near the coast, are essential to the success of this industry. An abundant supply of water for irrigation is indispensable. Finally, the large quantities of manure, sewage, etc., that are applied to the gardens can only be had in the large cities of the seaboard. At Tunis, Archimedean screws placed in the drains are said to be used for lifting sewage on to the fields.

Market gardens are generally irrigated by means of the noria. For the first irrigation of the season about 2 acre-inches of water are applied, while in each subsequent irrigation about 1.5 acre inches are used. Except in the case of artichokes, which will stand heavy flooding, the irrigation of truck crops demands considerable skill. The flow of the water should be gentle, and it should be allowed to stand at only a small depth on the fields.

By abundant watering and heavy manuring and fertilizing, crop is made to follow crop with hardly any intermission. From gardens thus managed the profits are very large. A high rent --often $75 or more an acre— is demanded for the best market-garden land in the vicinity of large cities. The gardener who leases the land usually lives upon it with his family. Each small plat into which the garden is divided is usually surrounded by a wind-break of reeds, either the living plants being set closely together to form a hedge or a fence being made of the dead stalks. Sorghum and Indian corn are also used for wind-breaks.

Globe artichokes are the truck crop that is most largely grown for export. "Gros vert de Laon" (Large Green of Laon) and "Violet précoce de Provence," or "Violet hatif" (Early Violet of Provence), are the most popular varieties for this purpose. Artichokes are harvested throughout the winter, from October until April, the same plant yielding several heads in succession. The average yield from an established field is about 30,000 marketable heads to the acre.

The consumption of potatoes in the colony being larger than the quantity produced, there is a considerable importation of this vegetable. Yet the production of early potatoes, especially of the Holland or Royal Kidney variety, for export to European markets, is an important phase of Algerian truck growing. The largest tubers are shipped to England, while the Paris markets prefer those of medium size. The best prices are obtained for potatoes marketed during Lent, especially just before Easter, when from $2 to $3.50 per 100 pounds is paid in Paris for Algerian potatoes.

Potatoes grown for consumption in the colony are sown in seed beds in January and February, and are set out about the end of April. Yields of 9,000 to 17,500 pounds per acre are obtained. The prices paid in Algerian markets for spring potatoes range from 50 to 85 cents per 100 pounds.

CEREALS.

The principal cereals of Algeria are wheat, barley, and oats, which are grown only as winter crops, and sorghum and Indian corn, which occupy the land in summer. Of these, wheat and barley are by far the most important. Algeria raises most of the grain needed for home consumption, importing only a relatively small quantity of soft wheat, used in bread making. The colony exports large quantities of wheat, barley, and oats. The area each year in cereal crops is estimated at 7,000,000 acres, which is about one-third of the entire cultivated area; hence much more land is in cereals than in all other crops combined. The mean annual production in the years 1890–1895 was 64,331,000 bushels, and the total value of the annual product of cereals averages $45,000,000.

While more or less grain is produced in every part of Algeria, the largest proportion is raised in the valleys of the coast region, notably in that of the Chéliff. Owing to the generally poor preparation of the land for cereals, the exhausted condition of much of the soil, and the fact that neither manuring nor rotation is generally practiced, the average yields are too low to make these crops as effective as they should be in contributing to the wealth of the colony. Much the greater part of the grain is grown by natives and gives yields averaging 30 per cent lower than those obtained by European colonists. In districts where improved methods of cultivation, notably in respect to deeper plowing, have been introduced by the colonists, yields much higher than the average are obtained. The country around Sidi bel Abbès, in extreme western Algeria, and Sétif, on the edge of the high plateau in the eastern part of the colony, is especially notable in this respect. The acreage in cereals that is in the hands of the natives, who depend for their crops entirely upon the rainfall and take no steps to conserve soil moisture, naturally varies much more from year to year than that farmed by Europeans.

WINTER CEREALS.

Wheat.—The average area in wheat during the ten years ended in 1893 was over 3,000,000 acres. Of this about three-fourths was owned and farmed by natives. The area in wheats of the hard or durum type, as compared with that in soft wheats, was as five to one. Less than 7 per cent of the area in wheat that is farmed by natives is devoted to soft wheats, while the European colonists grow hard and soft varieties in about equal proportion.

Algeria possesses excellent races of durum wheat, for which this part of Africa was famous even in Roman times.[a] Often several varieties are mixed together in one field, although the Arabs are generally acute in distinguishing the different types. Some of the most widely grown Algerian hard wheats have long, black beards. Some have short, others long heads. In some varieties the grain is short and thick, in others it is long and narrow. Types in which the grain is clear and amber colored are particularly valuable for making macaroni and semolina, considerable quantities of which are manufactured in the colony. Semolina forms the basis of "couscous," the national dish of the Arabs. Large quantities of Algerian hard wheats are also used at Marseille in the manufacture of macaroni and similar products, for which they are considered nearly, if not quite, equal to any in the world.

Authorities agree that the types of hard wheat already existing in the colony answer all requirements, and that it remains only to practice careful seed selection in order to improve the yield and to secure pure strains.

Several native races of soft wheats are also grown, including both bearded and beardless types. Soft wheats introduced from Europe have not, as a rule, proved a success. When grown near the coast they often fall a prey to rust, and are also liable to dry up without ripening when the hot weather begins in the spring. Recent experiments with the Richelle varieties, however, have indicated that this type is well adapted to Algerian conditions, giving good yields at several points.

Wheat, which is commonly broadcasted, is always sown in the fall, generally in November, after the rains have begun. In very dry years the soil is sometimes not in a condition for plowing in preparation for a crop of grain until well into the winter. This entails late sowing, which often greatly diminishes the yield obtained.

The harvest takes place in May or June, according to altitude, there being about four weeks' difference in time between the earliest and the latest localities in the colony. A native takes from three to five days to harvest an acre of wheat with a sickle, the implement that is still used in the greater part of Algeria. Recently, however, the combined reaper and binder has come into use in some places. Thrashing is done as soon as possible after the harvest and in a very primitive way. The sheaves are spread out on a floor of hardened clay, which is unsheltered from the air and sunshine. They are placed in concentric circles, with the heads turned inward. Horses, mules, or sometimes oxen, are then driven around on the floor, again and again, until the grain is beaten out. Sometimes the animals are hitched to a stone roller. Two men with three horses can thus thrash out 40 bushels of wheat a day, or if a roller is used, 70 bushels. About 5 cents a bushel is paid for thrashing wheat. The modern thrashing machines that are used in a few localities handle as much as 750 bushels in a day.

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[a] For descriptions and illustrations of the varieties of Algerian wheats, see C. S. Scofield, Bulletin No. 7, Bureau of Plant Industry, U. S. Department of Agriculture, 1902.

On the large estates wheat is cleaned by means of fans. Generally, however, a method is used which has been practiced for ages in the Mediterranean countries—that of pitching into the air the mixture of grain and chaff, the wind carrying away most of the latter. This can be done to advantage only on days when the wind is favorable. The straw is carefully saved and stacked, to be used as fodder, the stack being usually protected by a covering of dried mud mixed with short straw.

An ingenious contrivance for storing grain is in use among the Arabs. A piece of high ground having been selected, a hole 10 to 18 feet deep and 6 to 10 feet wide is dug, with a narrower opening. The interior is thoroughly dried by burning in it straw or brush, and is then lined with a layer of matting and straw about 6 inches deep. The carefully dried grain is packed closely into this cellar, the mouth of which is then covered with straw, matting, and finally with clay. Earth is then shoveled over the top to hide the whereabouts of the store. Grain can be kept for long periods without deterioration in this unique sort of granary. The Kabyles generally use earthenware jars for storing grain.

The average yield of wheat obtained by European colonists is about 15 bushels per acre, although under the most favorable conditions very much higher yields are sometimes had. The natives, on the other hand, are well satisfied with a yield of 8 or 9 bushels.

Wheat receives irrigation in only a few districts, notably in some of the large valleys of western Algeria. A marked increase in yield is the result. An irrigation in the early autumn at the rate of 3 or 4 acre-inches puts the land into good shape for plowing and sowing. The distribution of rainfall during the winter regulates subsequent irrigation, which does not exceed 2.5 acre-inches at each application.

Barley.—The area in barley averaged during the ten years ended in 1893 over 3,500,000 acres, 93 per cent of which was owned and cultivated by natives. Barley is even better adapted than wheat to native agriculture, being more drought resistant and requiring less preparation of the soil. The average yield for the entire colony is about 25 bushels per acre, but European colonists sometimes obtain 40 or 50 bushels. Barley forms a large part of the food of the native population and is also invaluable as forage, being almost the only grain that is fed to animals. Of the annual product of nearly 30,000,000 bushels, about one-eighth is exported. Much of this goes to northern France and to England, in which countries it is used in brewing. Algerian barleys are in high favor with European brewers, rather because of their cheapness than their quality. Improved races, like Chevalier, do not generally succeed in Algeria, being too liable to shatter; yet in some localities certain of the two-rowed European brewing barleys have given good yields. Naked varieties having an easily shelled grain are those generally grown by the natives to serve as food. They are very early and yield heavily.

Oats.—Compared with wheat and barley, oats are an unimportant crop in Algeria. The average annual acreage from 1884 to 1893 was only 114,000; i. e., less than 4 per cent of the area that was in wheat and less than 3 per cent of that in barley. Oats are grown almost exclusively by European colonists for export to Europe. Before the French conquest this cereal was practically unknown in Algeria. It is there considered by some authorities to be more resistant to drought and to salt in the soil than is either wheat or barley. It also requires less preparation of the soil and gives larger yields on newly cleared and poorly prepared land, being less likely to be choked by weeds. It can be sown up to the end of January—much later than wheat. The harvest takes place about the middle of May, and the average yield is 45 to 55 bushels per acre. Oats are said to be very susceptible in Algeria to the attacks of ergot and of rust, and for this reason the common winter oat is the only variety that can usually be grown at a profit.

SUMMER CEREALS.

Sorghum.—Two varieties of sorghum are grown, chiefly by the natives. These are white sorghum, the "bechna" of the Arabs, which is much used by the better class of Kabyles as a substitute for wheat flour in making "couscous" and bread; and black sorghum, or "dra," from the seeds of which the bread of the poorer natives is made. Black sorghum is also fed to animals; the leaves and stalks are a valuable resource at a season when green forage is scarce in Algeria.

If there is plenty of rain in April and May, and occasional showers in June, a good crop of sorghum can be made without irrigation. The heavier alluvial soils of the valley bottoms are considered best adapted to this crop, which is most grown in the mountain zone of the coast region. Sorghum is sown in April and ripens in August.

In good years 18 to 26 bushels of grain are obtained from an acre. During the ten years ended in 1893 the average area in sorghum was 75,000 acres.

Indian corn.—In the irrigated soils of the large valleys Indian corn is the most profitable summer cereal, but without a good water supply it is rarely a paying crop. For this reason, and because of the scarcity of manure, comparatively little is grown. The average area grown by natives during the ten years ended in 1893 was 20,000 acres. The variety known as "Quarantain" is esteemed for its earliness; "Caragua" for its large yields. Yields of 22 to 30 bushels per acre are obtained under irrigation, and the grain sells for about $1 per bushel. Algeria exports an insignificant quantity of this grain. Among the natives, especially in the Kabyle mountain districts, the roasted ears of maize are much esteemed as food, but with European colonists it is not in favor as a table vegetable.

FORAGE CROPS.

WILD FORAGE.

Two sorts of wild forage are to be distinguished—that of fallow fields and that of natural meadows.

Fallow-land forage.—After the removal of the winter crop of cereals wild plants of various sorts, including a great variety of Leguminosæ, spring up amid the stubble, especially when the autumn rains begin. This wild forage is generally most luxuriant during the first winter following the crop of grain. If the land is then left fallow for several years in succession a gradual deterioration of the wild forage, both in quality and in quantity, is observable. This can be prevented in large measure by occasional plowing. An application of farm manure at the rate of about 10 tons per acre will cause large yields of natural forage to be produced for two or three years, besides putting the land into excellent shape for two successive crops of cereals at the end of that period. Forage of this kind is generally pastured. If made into hay, it is usually fed on the farm, not being of a sort that is well adapted for baling and shipment.

In the oases of the Sahara, Bermuda grass, which the natives esteem as a forage plant, abounds. Almost every roadside and ditch bank is occupied by this grass. It is either grazed or is cut and fed green.

Forage of natural meadows and prairies.—The slopes of the hills and mountains of the coast region and the steppes of the high plateau, like the great plains of the Western States, are still covered in great part with a growth of grasses and other native plants, the value of which is enhanced by the presence of numerous species of vetch, clover, bur clover, and other Leguminosae. In the high plateau region large flocks of sheep and goats are pastured upon the natural herbage of the range, generally obtaining no other food.

Two sorts of natural meadow are to be distinguished—such as occupies land that is dry during the summer and such as is moist throughout the year. The first type covers by far the greater area. As in California and in countries where most of the rain falls during the winter months, the herbage is parched and brown in summer. With the first autumn rains, however, a sudden transformation takes place. The grass turns green as if by magic, and innumerable flowering plants spring up to beautify the land.

During October, November, and December, in the coast region, cattle and other stock are turned out to graze upon this tender young growth. At its best, 5 acres will support 6 head of cattle. During the latter part of the winter and in the spring it is more profitable to keep animals off the natural meadows, allowing a hay crop to be made. The greater part of the hay of the colony is produced by the dry meadows of the coast region. This is the hay that is purchased for the cavalry service of the army, and it is exported in considerable quantity to France in years when the crop of that country is short.

Artificial treatment of these natural meadows is rarely attempted, yet in many cases occasional irrigations, plowings, and manurings would very largely increase the yields obtained. In some places it might be advantageous to seed to wild grasses and forage plants of better quality than those now occupying the land. Without treatment of any kind, however, natural meadows will last a long time in good soil—sometimes twenty years without serious deterioration.

Meadows that are moist and green throughout the year produce more abundant but coarser forage. A cutting of hay is sometimes taken in spring from such meadows, but during the rest of the year they are used as pastures. They are a valuable resource in summer, when most of the grass land is scorched and dry.

In the coast region, hay is cut between the middle of April and the middle of May, the date of harvest varying considerably in different years and at different altitudes. The scythe is generally used, a native workman receiving from 65 to 75 cents for cutting an acre. There are some localities, like the Mitidja Valley, near Algiers, where the nature of the ground permits the use of a mowing machine, which reduces the cost to about 30 cents an acre. The average yield of hay from an acre of natural meadow is a little more than 1 ton.

In the drier valleys, like the Chéliff, the hay can be gathered into double swaths by the horserake the day after it is cut. Two or three days later it can be stacked in ricks. The rick ordinarily contains from 2 to 2½ tons, and is generally covered over with a thatch composed of the coarse grass known as "dyss" (Ampelodesmos). In case it is not convenient to place the rick on high ground, care is taken to surround it with a trench to carry off the rain water. One end of the rick always faces the west, the direction from which come the heaviest rainstorms. Hay is taken out as required at the other end. In favorable seasons 2½ tons of hay can be cut, cured, and stacked at an expense of less than $5. Hay is usually baled at a cost of about 5 cents per bale of 110 pounds. Near the larger cities it is hauled at the rate of about 30 cents a mile for an ordinary wagonload.

The prices paid for green forage and for hay in Algeria are based upon those offered by the government, which purchases large supplies for the cavalry service of the army. Various stipulations are made as to the quality of the forage to be delivered, and as these rules are also followed by most private buyers it will be interesting to enumerate some of them. Hay is rejected if it consists of but one valuable species, if it has been mixed after cutting, and if it contains various coarse weeds, notably thistles and plants of the parsnip family, poisonous plants, grasses like foxtail with sharp-pointed beards that injure the mouths of animals, various salt-loving weeds, and coarse marsh plants. The hay must, of course, be well cured, perfectly dry, and reasonably free from dust. A veterinary surgeon is detailed to inspect the hay before it is purchased.

CULTIVATED FORAGE.

The area which is adapted to the cultivation of forage plants in Algeria in summer is limited by the scantiness of the water supply at that season. Only in the valleys of the coast region, where irrigation is practiced, can such crops be grown on an important scale. Hence, in the total production of forage in the colony, cultivated plants play a much less important part than wild vegetation.

LEGUMINOUS CROPS.

Alfalfa, or lucern.—In Algeria, as in the arid part of the United States, alfalfa is the most valuable cultivated forage plant for perennial meadows. It is grown extensively in the irrigated valleys of the coast region. In the high plateau region little alfalfa is cultivated, but in some of the oases of the desert region it is the most important forage crop. Often in the coast region and always in the Sahara, alfalfa is grown in small, carefully tended patches. (Pl. V, fig. 2.) Fall sowing is generally practiced, although in elevated regions like that around Sétif, where early frosts are likely to occur, it is sometimes advisable to sow in the spring. In that case, however, the seed must be put in as early as possible, as otherwise the young plants suffer from the dry, hot weather of the later spring months.

The seed is often put in in rows, thus permitting the frequent cultivation and weeding of the fields. Otherwise, weeds, especially Bermuda grass and chicory, choke out the alfalfa. If sown broadcast an occasional harrowing is necessary to keep down the weeds. In case the fields are infested with dodder, the worst enemy of alfalfa in Algeria, these methods are not efficacious and other means must be taken to get rid of the pest. When the drill is used, about 18 pounds of seed to the acre are sown, but if broadcasted, about 22 pounds. Occasionally alfalfa is put in—preferably in January or February—with oats or barley, the latter serving as a cover crop for the young alfalfa; but this practice is condemned by the best authorities. Well-kept alfalfa meadows last twelve years or longer in Algeria.

Alfalfa is generally cut with a scythe. A native laborer can cut a little more than an acre a day, and receives about 45 cents an acre for the work. When a mowing machine is used the cost of cutting an acre is about 25 cents. In the oases of the Sahara a sort of sickle, with a nearly straight blade having a serrated edge, is used in cutting alfalfa.

The alfalfa crop is irrigated in Algeria both by flooding and by the furrow method. The latter requires less water, but gives the best results only in rather light soils. Flooding is the preferable method if the irrigating water is decidedly saline. From 3 to 4 acre-feet are put on at each irrigation.

Under irrigation, with a watering given every week or so throughout the summer, seven or eight cuttings can be taken, yielding a total of 7 or 8 tons of hay per acre. In soils of the littoral zone that retain a fair amount of natural moisture throughout the summer, alfalfa can sometimes be grown without irrigation. Three cuttings, aggregating 3 or 4 tons of hay, besides a considerable amount of pasturage, can be obtained under such conditions.

Most of the alfalfa in the coast region of Algeria is derived from the "Lucerne de Provence," a race that is grown in southeastern France. This showed itself from its first introduction to be perfectly adapted to conditions in that part of the colony. On the other hand, seed of alfalfa brought from Poitou, in western France, considerably north of Provence, does not succeed nearly so well in Algeria. A native drought-resistant strain is grown without irrigation in the neighborhood of Sétif, in the eastern part of the high plateau region. This variety may prove valuable in parts of the Western States where water for irrigating is not available. Turkestan alfalfa is being tested in Algeria and gives indication of being well adapted to the drier parts of the colony, particularly where the soils are somewhat saline. A fair stand has been obtained near Algiers without irrigation. The alfalfa that is grown in the oases of the Sahara appears to be decidedly resistant to the presence in the soil and irrigating water of large amounts of salt. (Pl. IV, fig. 2.) At Rouïba, near Algiers, the writers saw trial patches of alfalfa grown from seed obtained from the United States, from Tougourt in the Algerian Sahara, and from Turkestan all grown without irrigation. That from the Sahara seemed to thrive better at Rouïba than the American sort. The leaflets are shorter, broader, and hairier than those of the American plants.[a] The Turkestan alfalfa seemed to be earlier in maturing its seed than either of the other sorts. Doctor Trabut, the Government Botanist, thinks it will grow with less water than other kinds of alfalfa, and that it may consequently prove valuable for the steppe or high plateau region of central Algeria. Although the stand grown from Turkestan seed was less than one year old and had received no irrigation whatever, it was in fairly good condition. It is, however, very liable to infection with a rust (*Pseudopeziza trifolia*). Doctor Trabut finds this very frequently the case with plants brought from extremely arid regions into the more humid climate of the coast region in Algeria.

At Tougourt, in the Algerian Sahara, alfalfa is grown in most of the gardens, generally in the shade of date palms, in small patches from which other plants are excluded. It is usually grown in plats about 20 feet long and 6 feet wide, with a low ridge of bare soil 4 feet or so wide between each plat. The top of the ridge is usually white with an efflorescence of salts. The seed is sown in the autumn in rows a foot or so apart, barley being generally sown with the alfalfa and harvested the following spring. Thenceforward the alfalfa grows alone, and the stand is usually allowed to occupy the ground 4 or 5 years. It is then plowed under, and other cultures—generally garden vegetables—take its place. By this system the roots of the alfalfa plants probably do not have time to grow down into those depths of the subsoil which are saturated with water from the almost constant irrigation given in these gardens.

Every week during the summer one or two irrigations are given the alfalfa, which is tended as carefully as any garden vegetable. With such frequent irrigation a great number of cuttings is possible, especially as the stems are cut whenever they reach a height of about 2 feet. One native grower stated to the writers that he obtained as many as 24 cuttings during the year, but this was doubtless an exaggeration. The stems are cut off very close to the ground by means of a curved iron knife with serrated edge. They are tied in small bunches, 7 or 8 inches in diameter, the ends of which are placed in running water to keep the alfalfa fresh and attractive looking until it is ready to be sold. In the market at Tougourt such a bunch sells for 1 cent. So far as we could learn, alfalfa is always fed green in these oases, and is never made into hay. As it grows more or less throughout the winter, a sufficient supply of green forage can generally be obtained at all seasons.

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[a] At Yuma, Ariz., during the last two years, alfalfa from Turkestan, from the Algerian oases, and from Utah was grown side by side. No constant differences as to hairiness could be detected, but the leaflets of the Algerian seem to be generally broader than those of the Turkestan and Utah sorts. The Algerian sort seems also to grow faster and to promise larger yields than the others.

The alfalfa grown at Tougourt is of fine quality, succulent, thin stemmed, almost perfectly smooth, and having large, thin leaves. These qualities are doubtless mainly due to its being more or less shaded by the date palms and to the frequent watering it receives; for, at the experiment station at Rouïba, alfalfa from Tougourt had wiry stems and was hairier even than the American alfalfa grown beside it.

The crust of salt that often covers the ditch banks and strips of bare soil between the plats of alfalfa is sufficient evidence that the soil of the oases is very saline. The water used in irrigating likewise has a high salt content. Yet there are reasons for believing that the amount of salt to which the plants are actually exposed during germination and while still very young is not so great as would at first appear to be the case. The soil is light and loamy, and hence easily drained. Especial attention is given to this matter by the Arabs, drainage ditches being dug in the gardens at frequent intervals. These end blindly, as there is no natural outlet for them. Nevertheless, they must have a considerable degree of efficiency, for the alfalfa that is nearest the ditches is always in decidedly better condition than that which is farther away. With this provision for drainage and the very frequent irrigations given, it is probable that a very considerable amount of salt is leached out of the uppermost layers of the readily permeable soil. The date palms that shade the ground do their part by keeping down evaporation and thus retarding the return of the salts to the surface. Finally, the oasis soils are very rich in gypsum (calcium sulphate). This, as is well known, neutralizes to a considerable degree the harmful effect of other salts in the soil.

At the small oasis of Kuda-Asli, a few miles from Tougourt, alfalfa was found growing in the open, unshaded by palms or other trees. Examination of the soil showed that the plants were making a fairly good growth, although the stand was thin, in the presence of 1.36 per cent of salts in the first foot of soil. A good growth occurred in the presence of 0.9 per cent in the first and 0.5 per cent in the second foot. Finally, an excellent stand had been obtained in soil that contained from 0.4 to 0.6 per cent of salts in the first and second feet. The water used for irrigating this field contained 460 parts of salt per 100,000. The soil is a sandy loam, and is so full of gypsum that at a depth of about 2 feet a veritable hardpan of this substance is encountered. The presence of this dense stratum would be expected to interfere seriously with drainage, to which the texture of the soil is otherwise well adapted. Consequently, notwithstanding the conditions mentioned in the preceding paragraph as tending to counteract to some extent the effect of the salt, it would seem to be beyond question that this alfalfa is a distinctly resistant race, and is able to endure more salt in the soil than the alfalfa ordinarily grown in the United States. A small quantity of seed, reported to have been harvested last year from this patch, was secured for trial in this country.

Horse beans (*Vicia faba*).—The horse bean is a form of the broad bean, having more numerous and smaller pods. It requires deep, strong soils, containing a considerable amount of lime. When grown as a forage crop it is sown, sometimes mixed with barley or oats and sometimes alone, in rows about 2 feet apart. When the pods begin to turn brown the beans are harvested, spread upon the ground to dry, and then thrashed. The coarse, black straw, mixed with other forage, is fed to animals. The seeds are a valuable feed for milch cows, but discretion must be used in feeding them. Horse beans yield about 10 tons of green forage and 22 to 28 bushels of seed per acre.

Sulla (*Hedysarum coronarium*).—This leguminous plant has been highly recommended for Algeria, but is generally found difficult to grow and uncertain in yield. It is a deep rooting plant with erect stems 2 or 3 feet high. In the green state it is said not to be relished by animals; but if cut before flowering and made into hay or ensilage it constitutes an excellent forage. It is, however, very difficult to cure without losing the leaves. A further objection is that, while occupying the land two years, only one cutting can be taken. A good stand is nevertheless very productive, the average yield being, according to one authority, 5½ tons of hay to the acre.

Fenugreek (*Trigonella fœnum-græcum*).—This plant is very useful as a green manure crop, especially on tobacco land, for which purpose it is recommended to be sown with horse beans. The forage is much relished by cattle, but is said to give a disagreeable flavor to beef. The aromatic seeds are considered stimulating and fattening when added to other forage.

Berseem (*Trifolium alexandrinum*).—Berseem promises to be a valuable forage crop under irrigation in parts of Algeria where the winters are mild. It is most likely to succeed near the coast and in the oases of the Sahara, especially as a green manure crop for orchards. A good stand has been obtained near Algiers by sowing as early as July, four cuttings having been taken before the end of May.

Vetches.—Vetches are sometimes grown alone, but their trailing habit makes them difficult to cut. They are best handled when sown with barley or oats, this mixture forming one of the most valuable winter forage crops of the colony. Winter vetch (*Vicia sativa*) is the species most used, the hairy vetch (*V. villosa*) not having proved a success. The seed is sown in October and November at the rate of 70 pounds of vetch and 25 to 35 pounds of oats or barley to the acre. Vetch seed is rather scarce and high priced. The crop is harvested in April or early in May, when the vetch is in blossom and the cereal in milk. It is ordinarily fed green, although this can be done with perfect safety only after allowing it to wilt for a few hours. The mixed hay furnished by vetch with barley or oats is far superior to that of the natural meadows. In seasons when the rainfall has been plentiful, yields amounting to 1½ or 2 tons per acre are obtained. The largest yields are given by land that has previously been manured at the rate of about 1,000 cubic feet of farm manure to the acre. In very wet springs hay of this kind is difficult to cure, the vetch having a tendency to rot and drop its leaves. This crop leaves the land in excellent shape to be put into grain the following winter.

The botanical service of the Algerian government has been experimenting for several years with a variety of leguminous plants that promise to be more or less useful as forage and green manure crops. For the latter purpose, especially in vineyards, lupines, horse beans, fenugreek, vetches, peas, and lentils are recommended.

TREE CROPS AS FORAGE.

In the coast region, especially in the mountain zone, a number of trees contribute to the supply of forage. The Kabyles, having little room for field crops, feed the leaves of various trees to their animals. The leafy twigs of the olive, removed in pruning, and the leaves of the elm are thus utilized. Dried fig leaves serve in winter as a substitute for hay. In the handsome ash of his mountains the Kabyle has a veritable overhead meadow, which yields him a constant supply of green forage. The most important of arboreal forage plants is, however, the carob.

Carob, or St. John's bread.—The pods of this small tree, which resemble those of the American honey locust in having their seeds surrounded by a sweetish pulp, are highly esteemed throughout the Mediterranean region as food for cattle. There are also improved varieties, which are used in some countries as human food. The carob flourishes throughout the coast region of Algeria. European colonists have not given it much attention, but, especially in mountainous districts, it is much valued by the natives, who not only plant orchards of carobs, but, with a little care, succeed in obtaining good yields from wild trees. From Bougie, the seaport of Kabylia, considerable quantities of the pods are exported to Europe.

The best results are obtained by top-grafting scions of improved races upon seedling trees. The pollen is borne upon separate individuals, so that care must be taken to have male trees in every plantation. The largest yields are obtained by following the Spanish practice of grafting a branch from a male tree upon the base of the trunk of a fruiting individual. The establishment of a plantation of carobs is therefore a somewhat troublesome undertaking. After six years the trees, as a rule, begin to bear fairly well. In fifteen or twenty years they are in full production, single trees of that age sometimes yielding 650 pounds of pods. In some races the pods are 10 inches long, their sugar content sometimes reaching 44 per cent.

The harvest takes place at the beginning of autumn. Poles are used to knock down the pods, which are spread out to dry in the shade. When thoroughly cured they are collected into stacks, which must be opened from time to time to prevent fermentation. Carobs after being crushed and mixed with coarser fodder constitute a very palatable and nourishing ration for live stock, especially for work animals.

Indian fig.—The Indian fig, or prickly pear, (*Opuntia ficus-indica* and *O. tuna*) is thoroughly at home in the coast region of Algeria, where it frequently attains the size of a small tree. Spineless varieties are a valuable resource for feeding live stock in summer, when green forage is generally scarce.

The Indian fig will grow in the stoniest, most sterile soils, and under such conditions will produce from 9 to 11 tons of green forage every two years. In good land still larger yields are obtained. This plant responds well to manuring and to a moderate amount of irrigation.

The feeding value of the large flattened joints of the stem is not great, about 65 per cent of their weight being water. For this very reason, however, they form an excellent ration, especially for milch cows, when mixed with dry feed, such as chopped straw, bran, oil cake, and the pods of the carob tree. A little salt is often added to the mixture. Grandeau, the well-known agronomist, speaks of the Indian fig as the "forage beet of warm regions." It is estimated that 75 pounds of the stems, together with an equal weight of straw, are equivalent in feeding value to 100 pounds of good hay. Hogs are extremely fond of the fruits.

MISCELLANEOUS CROPS.

TOBACCO.

Tobacco has long been cultivated in Algeria, where oriental types were grown by the natives before the French occupation. The first colonists introduced a considerable number of varieties, but only one of these, believed to be derived from Paraguay tobacco, is now extensively grown. The area annually planted to tobacco amounts at present to only 12,000 to 15,000 acres, most of which is in the Department of Algiers. The colony is said to produce each year from 11 to 13 million pounds of tobacco. This would mean an average yield per acre of 888 pounds, which is much higher than the average in most tobacco-growing countries. The yield from irrigated is said to be about double that from unirrigated land.

The quality of the product depends largely upon the locality. Some of the best Algerian tobacco is grown in the Kabyle mountain district, where the soils seem to be peculiarly well adapted to this crop. Much of the product of western Algeria is defective in combustibility, being grown in saline land, where it absorbs considerable salt. Soils containing more than 1 part per 1,000 of sodium chlorid are considered unsuitable for tobacco. Excessive irrigation also injures the quality, although increasing the yield, of much of the tobacco grown in that part of the colony. The finest tobacco is generally grown without irrigation. In the oases of the Sahara, snuff tobacco is cultivated by the natives.

The type of tobacco ordinarily grown in the colony has a wide, very compact flower cluster and crowded narrow leaves. Plants of this type are thought to suffer less from wind than broader leaved forms. For several years the botanical service of the colony has been carrying on experiments in crossing various high-grade foreign tobaccos with this Algerian type. It has been found that while most of the uncrossed foreign varieties are not well adapted to Algerian conditions, the crosses seem almost as much at home as the Algerian parent, and often retain the desirable qualities of the imported variety.

The best Algerian tobacco has an agreeable, sweet aroma, suggesting that of some Turkish varieties. It is especially suitable for cigarettes and smoking tobacco, very little being used in the manufacture of cigars.

FIBER PLANTS.

The production of vegetable fibers on a commercial scale is now limited to alfa grass and the dwarf palm, the latter yielding "vegetable horse hair." As neither of these plants is cultivated, they are discussed in this report under the head of "Forest products."

Flax, jute, hemp, sisal hemp, manila hemp, and ramie have all been tried from time to time, but the cultivation of none of these fiber plants has passed the experimental stage. The scarcity of water in summer is generally the most serious obstacle, but there are also other practical difficulties. The Algerian government is now offering a bounty to growers of flax and hemp. Cotton growing was an important industry during the American civil war, but has since been abandoned.

PERFUME PLANTS.

In the coast region, particularly in the littoral zone, the growing of plants used in the manufacture of perfumery is one of the most important of the minor agricultural industries.

The principal perfume plant of the colony is the rose geranium. It is propagated by cuttings, which are set out in December or January. Plantations, once established, continue to yield profitable crops for from four to eight years, those in heavier soils being the more lasting. Under irrigation three crops can be obtained each year, and the average total yield from an acre is said to be about 12 tons of leaves annually. The oil produced in one year by an acre of rose geranium is estimated to average about 25 pounds, but in rare cases is as high as 50 pounds. Some Algerian distilleries have an annual output of 2 tons of oil of geranium. In recent years the fall in price of this perfume has caused the acreage in rose geranium to be greatly reduced.

Among plants grown for the perfume obtained from their flowers are *Acacia farnesiana* and the bitter orange (bigarade). The latter yields orange-flower water and "Essence de Néroli." The leaves of *Eucalyptus globulus* are also used to some extent in making perfumery.

LIVE STOCK.

The live-stock industry is very largely in the hands of the Arabs. They raise practically all the sheep, goats, camels, horses, and donkeys, and much the greater number of the cattle of Algeria. The colonists usually buy from the natives the beef cattle which they fatten, and also their work animals. The natural forage of the country is, as has been previously stated, the principal resource of the raiser of live stock, cultivated forage plants playing an important part only in irrigated districts of the coast region. There the business of fattening cattle that have been raised on the wild forage of the hillsides and steppes has attained some importance.

The high plateau region, like many districts in the western part of the United States, is for the most part a "range," where animals are driven from place to place and pastured upon the natural herbage. Sheep and goats in vast numbers—about three-fifths of the total number in the colony—graze on the elevated plains. Cattle, however, are few. The flocks are the property of nomadic Arabs, Europeans having taken no part in the pastoral system of the steppe region, except in so far as to purchase the product. The conditions as to climate and food supply are often severe. In summer the herbage, except in moist depressions, is parched and brown, and water is very scarce, while the winters are rigorous. As yet, little has been done in the way of providing shelter and artificial sources of water for animals pastured on the high plateau.

Sheep and goats furnish the inhabitants of the high plateau region with almost everything they use, affording skins for their tents and vessels for holding water, wool and leather for their clothing, and meat and milk for their food. Goats are raised chiefly to supply the necessities of the natives, although their skins are exported in considerable quantity. Sheep, on the other hand, furnish a very important export trade in meat, hides, and wool. It is estimated that between 6 and 10 million sheep and 3½ million goats are annually pastured upon the elevated plains of Algeria.

CATTLE.

The greater number of the cattle raised in Algeria belong to a well-marked North African type —perhaps a subtype of the Spanish cattle—of which various races are distinguished. The best defined of these are the Guelma and the Moroccan races. They are rather small in size and of good shape, with rather long body, full flanks, large, well-formed chest, rather small belly, and erect, curved horns. In color they are usually dark, having black head and legs and dark gray, fawn-colored, or red back and flanks. They are hardy animals, habituated to the severe conditions under which they ordinarily live. Owing to the small amount of food obtainable during the long, dry summer they are small and slow in maturing, requiring usually six years to reach full development. In spring, when the natural pasturage is abundant, and at other seasons, if supplied with cultivated forage, they fatten rapidly. If given plenty of green forage and a small amount of grain, a steer can usually put on 400 pounds of meat without difficulty. When well treated, Algerian cattle make excellent work animals, but the cows are generally poor milkers.

Cattle are purchased from the Arabs for fattening, usually in the late summer or early autumn, and at a price of $9 to $13 per head. They are pastured during late autumn and winter on uncleared land or fallow grain fields. At the beginning of spring they are usually very thin, but fatten rapidly from that time on. After three months of spring pasturage they often weigh enough to be sent to the butcher. A large number go to the markets of the colony, but there is also a considerable export of live cattle. At Marseille, Algerian cattle sell on the hoof at the rate of $9.50 to $10.50 per 100 pounds. At this price there is a good profit in cattle fattened in the pasture, but not when fattened in the stable.

Improved European races of cattle are not generally adapted to the trying climatic conditions of Algeria; nor can they, like the native cattle, endure well the periods of scanty food supply that these conditions impose. Only in the restricted areas, where irrigation allows of the constant production of forage of good quality, is anything to be expected from the introduction of foreign breeds. In such localities crossing high-bred races with the hardy Algerian cattle may prove advantageous in increasing the milk and beef producing capabilities of the latter.

HORSES.

It is estimated that there are 210,000 horses in Algeria, four-fifths of which are the property of natives. Algerian horses belong to the African type, with an admixture of Arabian blood. In its most typical form the horse of Algeria is rather small and light, but is very hardy and capable of much work. The Arabs generally use horses to draw their plows.

The eastern part of the high plateau region is the center of horse breeding in Algeria. The Arabs of the Sahara obtain almost all their horses from that district. The industry of raising horses is, however, on the decline, the prices brought by good animals having fallen 100 per cent or more in the past ten or fifteen years. A mare of good pedigree and known for the excellence of her progeny can now be bought for about $150. The increasing popularity of the mule as a work animal, both among natives and Europeans, is partly responsible for this state of affairs.

DONKEYS.

There are some 275,000 donkeys in Algeria, almost all of which are the property of natives. In the coast region they have largely replaced the camel as a beast of burden, although the latter still retains its usefulness in the high plateau and desert regions. Wherever the use of wagons for transportation is precluded by the lack of good roads the donkey is employed.

MULES.

Of the 150,000 mules that existed in Algeria in 1900, less than one-fifth belonged to Europeans. The high plateau region, around Sétif and Constantine, produces the best mules of the colony. Mules are used by European farmers to draw their wagons and plows, and by the natives for riding and for carrying loads. A hardier and more robust animal is obtained if the donkey parent is of Algerian rather than of European origin.

CAMELS.

It is the one-humped Arabian camel, or dromedary, that is common in Algeria. The Mehari race of the dromedary is especially adapted to travel in the Sahara, making, without difficulty, marches of 70 miles a day for several successive days. Camels are, of course, well known for their endurance, getting along for considerable periods without food or water. They can carry for long distances loads weighing 800 pounds and more. Camels are raised and are used only by the Arabs. A good animal will sometimes bring $60. In agricultural work the camel is of practically no importance, except as a means of transportation.

SHEEP.

In is estimated that in ordinary years the flocks of the colony represent a total value of $28,500,000, which is almost wholly the property of natives.

Three principal races of native sheep are distinguished in Algeria—the Kabyle, or Berber, which is peculiar to the mountain region; the Barbary, a large-tailed race, which is most common in eastern Algeria; and, best of the three, the Arab, which is rapidly supplanting the others. The Arab race is that which is usually found in the large valleys and plains of the coast region and also in the high plateau region. The small, slender tail is a distinguishing mark of this race. The head is sometimes brown or black and sometimes white, the white-headed type being the finest of Algerian sheep. The short, dense, more or less curly, rather fine fleece of the Arab sheep is in marked contrast to the long, straight, coarse wool, resembling goat hair, with which the Kabyle sheep is covered. The best quality of wool is produced in the larger valleys of the coast region.

The colonists formerly purchased from the natives nearly all the sheep they fattened. There is a growing tendency, however, to raise sheep on the farms of the coast region. Sheep that are bred where they are fattened are found to give when only 14 months old from 6½ to 9 pounds more meat than 2½-year-old sheep that have been purchased from native shepherds.

The white-headed Arab type of Algerian sheep shows an approach to the Merino. Crossing with the latter race is found to give a superior animal, which produces not only more meat, but wool that is better in quality and about 50 per cent greater in quantity. Careful selection among the mixed native races can also be counted upon to enhance greatly the value of the meat and wool produced by Algerian flocks.

GOATS.

The natives usually pasture goats together with sheep and cattle, but this is from every point of view a bad practice. Except for their large milk production, goats are not held in much esteem among the European colonists. To the natives, however, their skins, hair, and meat are invaluable. The fact that they can pick up a living in places where cattle or even sheep can not obtain sufficient food is a strong point in their favor. Two races occur in Algeria—the Kabyle goat, with long hair and horns, and the hornless Arab race, which gives more milk.

FORESTRY.

GENERAL CONDITIONS.

According to official estimates there are about 8,000,000 acres of forest land in Algeria, of which about 60 per cent belongs to the coast region, or Tell. The term "forest land" is used, however, in its widest sense, land bearing a shrubby growth of lentisk, dwarf oak, olive, myrtle, dwarf palm, etc., such as occupies vast expanses in the coast region, being included. The steppes of the high plateau region, which are covered with coarse grasses and herbs, possess no forest in the strict sense of the word. Only here and there, in depressions, straggling shrubs and small trees of betoom (*Pistacia atlantica*) and of juniper are found. Yet considerable areas of this character are officially designated as "forest." In the desert region, except on the highest mountains, nothing resembling a forest occurs, the native vegetation being limited to scattered shrubs and coarse grasses, with an ephemeral growth of small herbs that spring up after the infrequent showers. The true natural forest is confined almost wholly to the mountains, especially those of the coast region and of the eastern part of the high plateau.

The forests of the colony are of various types, which owe their characteristics not only to natural conditions of climate and of soil, but also to the direct or indirect agency of man. In many localities only scattered old trees remain, the intervening spaces being occupied by brush or by a carpet of grass. Sometimes there is almost no vegetation except an occasional tree, and in such land active erosion takes place. This condition has probably been brought about for the most part by reckless exploitation or by fires which are often kindled by the natives in order to provide their flocks with the more abundant pasturage that springs up afterwards. The admission of flocks into the public forest reserves is frequently a cause of the rapid disappearance of the young trees, especially when goats are pastured among them. On the other hand, particularly at high elevations in the mountains, there are dense forests where the trees reproduce themselves freely; but this type is the exception rather than the rule.

The forests also differ in the diversity of species composing them. Sometimes large areas, especially at the higher elevations, are occupied almost solely by a single species. Sometimes while one kind of tree predominates, others are present in smaller numbers. Less often several species are mingled together in nearly equal proportion, forests of this type being most frequent in the littoral zone.

The composition of Algerian forests as to species depends upon climatic and soil conditions, and upon the altitude. Well-defined zones, each characterized by some one predominant species, succeed each other at different elevations in the mountains. From sea level up to about 2,500 feet, cork oak, olive, and Aleppo pine are the principal elements, the last being the most widely distributed tree in the colony. Here the forest is most apt to be mixed with a shrubby growth, made up of various species characteristic of the so-called "maquis" of the Mediterranean region.

From 2,500 to 4,000 feet, *Quercus ballota*, a kind of live oak, often predominates. The sweet acorns of this tree are much relished by the Kabyles, who make a practice of selecting and preserving such individual trees as bear the best nuts.

Between 3,500 and 6,000 feet, the handsome Zen oak (*Quercus lusitanica* var.) forms heavy forests of good-sized trees, usually 50 to 70 feet high. In one locality Zen oak covers an area of 100,000 acres.

Finally, at elevations of 4,000 to 6,000 feet, occur magnificent forests of Atlas cedar, a short-leaved variety of the cedar of Lebanon. The total area occupied by this tree approximates 90,000 acres. It usually forms an open forest, the trees being separated by expanses of grass land and low brush. Unfortunately, this superb tree shows very little tendency to reproduce itself. The Atlas cedar lives to a very great age. Individual trees of unusual size, distinguished, like some of the "big trees" of the Sierra Nevada, by particular names, are made the goals of pilgrimages by tourists.

Besides the species already enumerated, the following are noteworthy, either for their abundance or their economic value: Ash (*Fraxinus kabylica*), arbor vitæ (*Callitris quadrivalvis*), juniper (*Juniperus oxycedrus* and *J. phœnicea*), and fir (*Abies numidica*). The chestnut, almond, cherry, fig, and carob are all represented in the mountains of Algeria by wild forms.

Especially in the large valleys of the coast region, such as the Habra, Chéliff, and Mitidja, the planting of trees to furnish timber for construction and firewood, as well as for shade and protection against winds, has been extensively practiced. Species of Eucalyptus, notably *E. globulus* (blue gum) and *E. rostrata* (red gum), are most used. The latter has proved to be the better adapted to Algerian conditions, and is now rapidly replacing the blue gum. *Eucalyptus robustus* and, to a lesser degree, *E. occidentalis* are said to be the species that succeed best in saline soils. The colonists began in 1860 to plant Eucalyptus in large numbers, but when it became apparent that the value of the wood for building purposes had been overestimated, these trees somewhat declined in favor. Nowadays, however, their utility in other respects is generally appreciated.

A large part of the forest land of Algeria, including vast areas covered with brush and grasses, as well as much true forest, is owned by the government. A code of forest laws modeled upon those of France governs their administration. The penalties against starting forest fires are very severe, but are difficult to enforce, because of the mountainous character of much of the country, the frequent absence of facilities for travel, and the active or passive opposition of the Arab population, which is largely devoted to raising live stock. It has been necessary to open much of the public domain to flocks owned by the natives. Although regulations have been established which, if strictly enforced, would prevent serious damage from this cause, as a matter of fact the forests often suffer severely. But in some areas, where it has been possible to prevent grazing during longer or shorter periods, considerable reforestation has taken place.

Forest land belonging to the government, particularly such as bears a growth of cork oak or of alfa, is often leased for a nominal rental to companies or to individuals who exploit these products. Some of the most valuable forested areas are the private property either of Europeans or of natives.

FOREST PRODUCTS.

Following the loose application of the term "forest" that prevails in Algeria, there will be discussed under this head commercial products that are furnished not only by trees, but also by the grass known as alfa, and by the dwarf palm. As a justification for this arrangement, it should be stated that both of these plants occupy extensive areas which are officially designated as forest land, and that neither of them is ever cultivated.

FUEL.

Most of the trees—and many of the shrubs—native in Algeria supply the inhabitants with firewood and with charcoal, which, as in all Mediterranean countries, is much used for fuel. The expense of clearing land is often partly met by the sale of the firewood and charcoal obtained in the process. In some of the large valleys of the coast region, where there is little natural tree growth, plantations of eucalyptus are useful as a source of fuel.

TIMBER.

Most of the wood for construction used in Algeria is imported from northern Europe and from Austria, the natural resources of the colony in this respect having been little developed. Probably this is partly due to the scarcity of water and the consequent absence of large perennial streams, which render difficult and expensive the transportation of logs from the mountains. Artificial plantations have been of little value as a source of building timber, eucalyptus wood particularly being deficient in durability.

Some of the native timber trees promise well, and may some day come into extensive use. Live oak (*Quercus ballota*) and Zen oak (*Q. lusitanica*) furnish an exceedingly hard wood that is somewhat difficult to work. Wood of the Zen oak is particularly valuable for making brandy casks. The extremely durable wood of the Atlas cedar is excellent for railway ties, and is sometimes used in cabinetmaking, its pleasant odor enhancing its value for the latter purpose. Long immersion in water renders it almost indestructible. Arbor vitæ has a beautifully colored wood, variegated with numerous knots, and is highly esteemed by cabinetmakers.

CORK.

The total area occupied by the cork oak in Algeria is estimated at 1,025,000 acres, of which 725,000 acres are being exploited at the present time. About 60 per cent of the entire area belongs to the public domain. The total production of cork in 1899 amounted to 15,900 tons. It is estimated that if all the cork oak of the colony were in a productive state an annual revenue of from $2,000,000 to $4,000,000 could be derived from this source.

The cork oak ranges from sea level up to about 4,500 feet, the largest forests being found in the mountains of the coast region in northeastern Algeria, the western part of the colony being generally too dry for this tree. It avoids limestone, attaining its highest development on soils derived from the Numidian sandstone, where these soils are underlain by a subsoil heavy enough to retain considerable water.

The tree is usually of medium height and size, but its trunk sometimes reaches a circumference of more than 30 feet. The largest individuals are invariably hollow. The crooked trunk and irregular branching give this tree an unkempt, straggling appearance. The evergreen foliage resembles that of the live oak of the Southern States. The wood is of little value, the important products of this tree being cork and tan bark.

Well-managed forests of cork oak are kept free from undergrowth, thus diminishing the likelihood of loss from fire, to which they are peculiarly liable. The danger is greatest in September, when the sirocco is blowing. Fires are often wantonly kindled in the oak forests by malcontent natives and spread with terrible rapidity, frequently devastating vast areas. Only natural forests are exploited in Algeria, no attempt ever having been made to establish artificial plantations.

In bringing a forest of cork oak into condition for exploitation the first step is to remove the layer of old or "male" cork which forms under natural conditions. This operation, which requires considerable skill, is performed in the spring when the sap is beginning to rise. The subsequent yield depends largely upon the way in which this work of "demasclage" is done. It is advisable to put back into place the layer thus removed, fastening it around the trunk by means of wire and leaving it there for about two years; otherwise the trees are very liable to injury from dry, hot winds and from fire. Wrapping the trees in this way also prevents a second development of the worthless male cork.

The new cork which now begins to form is alone of commercial value. It is deposited at the rate of from 0.04 to 0.12 inch annually, and the first harvest is taken when the layer of cork has reached a thickness of about 1 inch. Thereafter the cork is removed every eight or ten years, the later crops yielding a better product than the earlier ones. The expense of each harvest from a single tree is about 2 cents.

Individual trees differ greatly in the rate at which cork is formed. As a rule, the best product is that which develops most slowly. Rapidly growing cork is more abundantly veined with loose tissue, which diminishes its value. The cork is sometimes seriously injured on the tree by the ravages of ants, which build galleries in it. The tree has also other insect enemies.

The cork, when cut, rolls up into tubes of the size of the trunk from which it was taken. It is first pressed out into sheets, then boiled, and finally the crust of bark is removed by scraping. Boiling increases the bulk by about one-fifth and renders the cork more elastic.

An acre of cork oak in full production yields a net annual revenue of about $2. The product from a single tree is worth from 4 to 10 cents a year after all expenses are deducted. Algerian cork sells at from 3½ to 10 cents per pound.

TAN BARK.

The forests of Algeria furnish a large amount of bark for tanning. The annual export of tan bark, chiefly to Great Britain and Italy, amounts to about $200,000. A considerable quantity is also consumed in the colony itself, the manufacture of leather being an important industry among the natives.

Most of this bark is furnished by several species of oak. The Kermes oak (*Quercus coccifera*) ranks first in production, the bark of the root being used. The forests of cork oak, especially those belonging to natives, also furnish a large quantity. The collection of the bark is generally done in such a way as to kill the tree, although if proper precautions were observed the forests could be exploited for tan bark without diminishing their production of cork. The bark of this oak yields about 19 per cent of tannin. A single tree will furnish several hundred pounds of bark, a ton of which sells for from $22.50 to $37.50.

Various tannin-producing plants, such as Australian species of acacia, which furnish the wattle bark of commerce, canaigre, and the Valonia oak, have been recommended for cultivation in Algeria, but none of these has yet become of practical importance. In Tunis experiments are being made by the government in the cultivation of the Sicilian sumac (*Rhus coriaria*), the powdered leaves of which are a valuable material for tanning.

ALFA.

The Arabs use the word "halfa" in much the same way as the term "bunch grass" is used in the western United States to designate any coarse, rush-like grass that grows in tufts. The "alfa" of the French colonists signifies, however, only the species known in Spain as "esparto" (*Stipa tenacissima*). The tough, fibrous leaves of this grass are used in manufacturing paper, basket ware, hats, cordage, etc. It is a long-lived plant, having strong, much branched rootstocks, which give it a good hold upon the soil. The young plant forms a dense tuft, which later takes the form of a hollow circle, as the stems in the center die out. This in turn becomes broken up into separate tufts, each of which is the starting point of a new circle. The leaves are like those of many other so-called "steppe" grasses, being flat and green during the rainy period, but turning yellowish white and rolling up into quills when the dry season sets in. They average from 20 to 30 inches in length, and end in long, sharp points. The leaves last about two years. The older ones are often infested with fungi, which usually attack first the point of the leaf.

Alfa grass covers large areas in Spain and in northern Africa. In Algeria it is most characteristic of the high plateau region, where it often occupies, almost alone, enormous expanses of the undulating plains, forming the so-called "sea of alfa." It is not, however, confined to the high plateau, and even reaches the seashore in extreme western Algeria. It ascends in the mountains to a maximum elevation of 6,000 feet. Where the average annual rainfall exceeds 20 inches a year alfa does not flourish. It prefers a dry, sandy soil, and will not endure the presence of any considerable amount of salt. In moist depressions, where the soil is clayey, other species take its place.

It is difficult to obtain an accurate estimate of the total area occupied in Algeria by this grass. Some authorities give 12,500,000 acres in the high plateau region alone, but this is doubtless an exaggeration. The alfa land of the colony belongs partly to the government and partly to individuals or private companies. The government concedes the right of exploitation for the modest sum of about 1 cent per acre. The holders of concessions, in their turn, usually sublet their rights to a contractor.

A stand of alfa in its natural condition is less valuable than one from which the leaves are regularly harvested. In the former case there are many more or less worthless old leaves mixed with the young leaves. When the exploitation of a stand is begun it is customary to burn it over so as to destroy the coarse old leaves. Thereafter, if the crop is harvested every season, only small, fine leaves, much stronger and more uniform in length than the older ones, are obtained. By firing a tract repeatedly for several successive years "white alfa," with extremely fine, flexible, light-colored leaves, is produced. Long-continued exploitation of a stand, without allowing it any rest, greatly weakens the plants. In fact, alfa has in this way been virtually exterminated in some of the more accessible areas.

As attempts to form artificial plantations of alfa have not so far proved successful, there is danger of the total annihilation of this industry, which, after stock raising, is the mainstay of the population of the high plateau region. To prevent this consummation, a closed season of four months has been established by law. Alfa can not be legally harvested or purchased from gatherers in the high plateau region during the months of March, April, May, and June. In the coast region the closed season extends from the middle of January to the middle of May.

The contractor who undertakes to harvest alfa puts up a barn on the tract and secures Spanish or Arab laborers, whom he provides with food and water, to gather the leaves. Alfa harvesters sometimes come long distances with their families, attracted by the high prices paid for this work. A good laborer can gather, in a day, 650 to 900 pounds of green leaves, for which he is paid nowadays at the rate of about 18 cents per 100 pounds.

The gathering of alfa is still done exactly as classical writers described the process in the times of the Romans. The harvester starts out early in the morning and selects a spot where there is plenty of the grass. Fastened to his left hand by a leather thong is a stick about 16 inches long. With his right hand he seizes a cluster of the tough leaves, rolls them obliquely around the stick, and gives a strong pull with both hands. This breaks off most of the blades at the point where they join the sheaths, although some of the sheaths generally come up with the blades and must be broken off by a second pull. The leaves are packed as fast as they are gathered into baskets, which are then carried to the barn. The green alfa sent in by each harvester is weighed and is then stacked in ricks. When dry it is sorted to remove any sheaths and branches that may still be attached to the leaves. It is baled under a hydraulic press and the bales are secured with hoops. The product is then ready for transportation to the nearest seaport.

Algeria now exports annually nearly 80,000 tons of alfa, which is approximately 35 per cent of the entire output of alfa-producing countries. The total value of the export from Algeria is nearly $1,500,000 a year. England is the largest purchaser, taking, indeed, nearly 90 per cent of the entire world's supply of alfa. France and Belgium also import considerable quantities.

More than 90 per cent of the total amount of alfa produced is used in the manufacture of superior grades of paper. Paper made from the leaves of alfa is strong, transparent, of a silky texture, and very light in proportion to its thickness. It is preferred to any other for printing costly books and engravings.

The best grades of alfa, however, are used in making basket ware, hats, and matting, bringing a price almost twice as great as is paid for that used in paper manufacture. The finest baskets are made from the "white alfa." Rope, brooms, and other articles are also manufactured from the leaves of this grass.

DWARF PALM.

The leaves of the dwarf palm (*Chamærops hystrix*) are much used by the Arabs for thatching their huts, making crates in which fruit is packed, etc.; but the only product of this plant which enters largely into commerce is the fiber, which constitutes about 40 per cent of the weight of the fresh leaves. Under the name of "vegetable hair" this fiber is exported in considerable quantity. It is used for stuffing mattresses and upholstered furniture. A cheap grade of rope, selling for about 80 cents per 100 pounds, is also made from it. The dwarf palm, like alfa, is never cultivated, only the natural growth being exploited. While alfa is preeminently a plant of the high plateau the dwarf palm belongs to the coast region, where it formerly covered vast expanses. Although still abundant, this plant is rapidly disappearing as more and more land is brought into cultivation. Commercial exploitation has helped to accelerate its destruction, there being numerous factories in Algeria for separating the fiber.

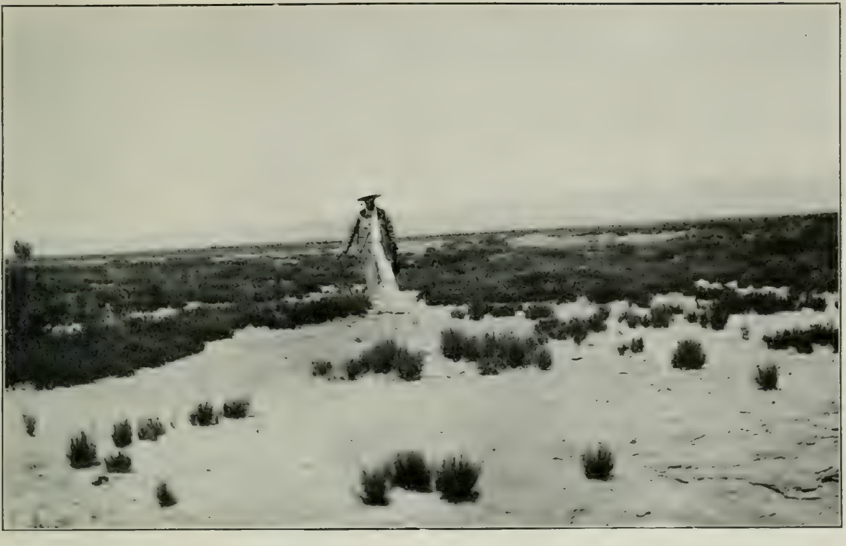

FIG. 1.—SALT LAND, NEAR RELIZANE, IN THE COAST REGION OF ALGERIA.

This land, formerly cultivated, is now covered with a growth of salt-loving weeds.

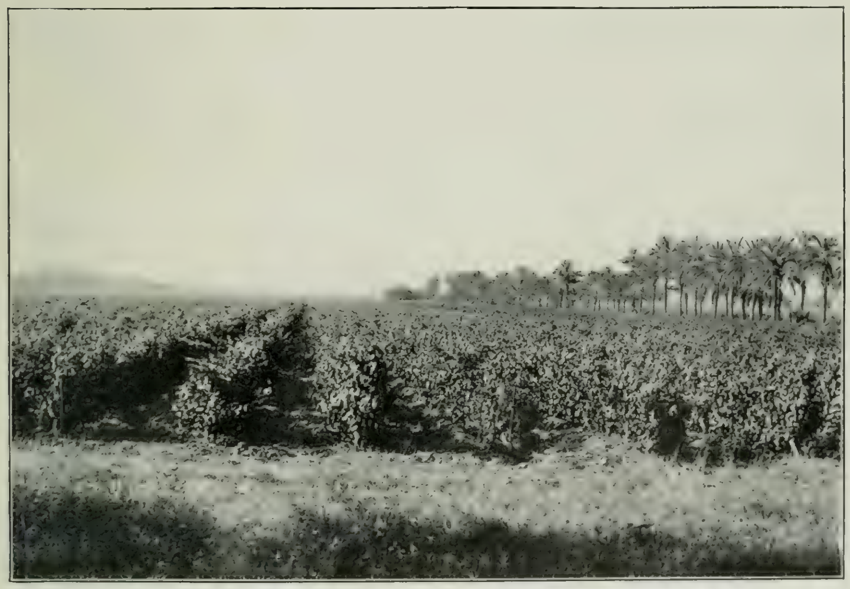

FIG. 2.—VINEYARD OF WINE GRAPES IN THE MITIDJA PLAIN, NEAR ALGIERS.

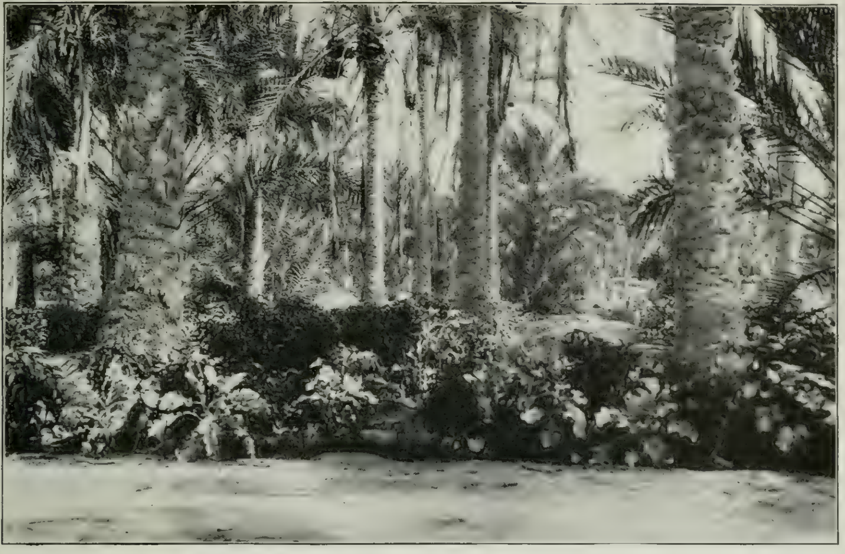

FIG. 1.—GARDEN OF THE KAÏD AT TOUGOURT, SHOWING CABBAGE, PEPPERS, AND OTHER VEGETABLES GROWN IN THE SHADE OF THE PALMS.

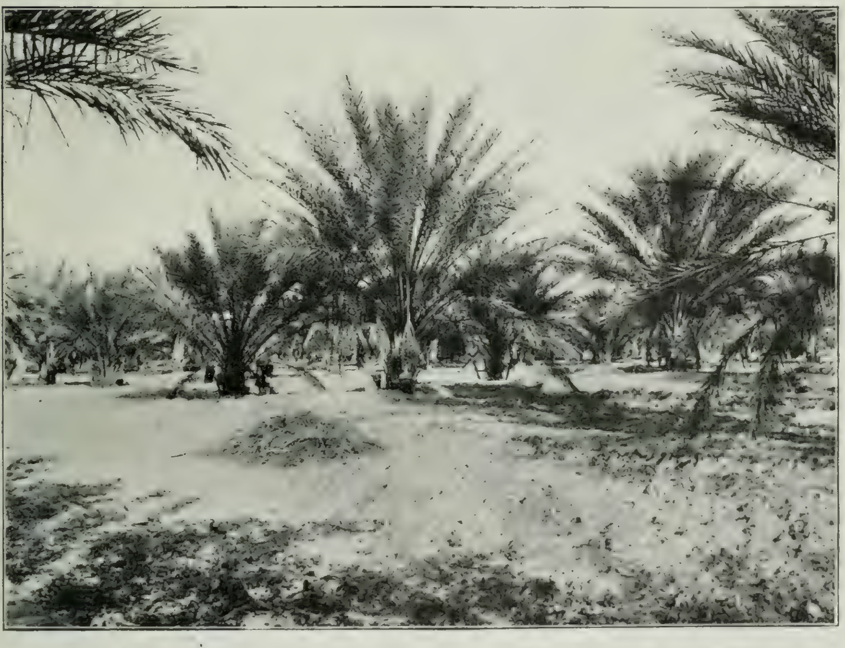

FIG. 2.—DATE PALMS PLANTED IN VERY SALTY LAND BY A FRENCH COMPANY AT OURLANA, IN THE SAHARA.

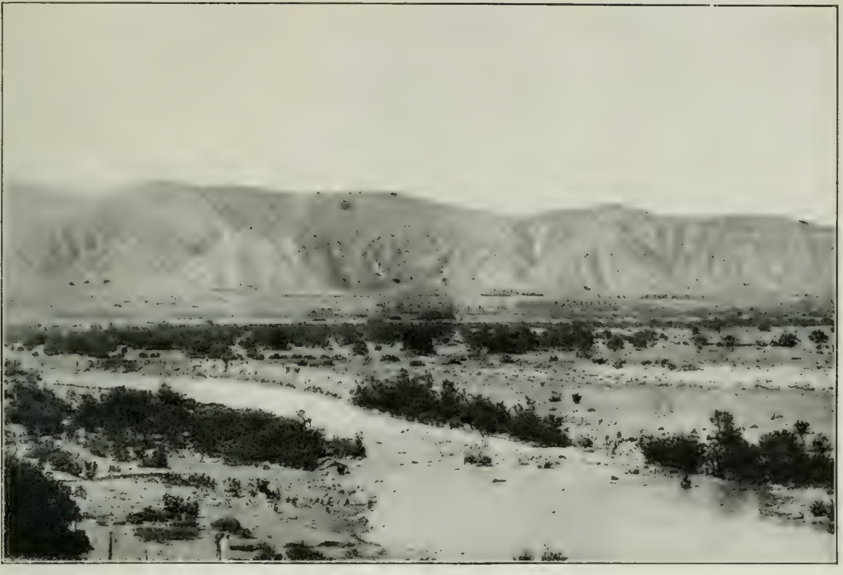

FIG. 1.—VALLEY OF THE HABRA BELOW THE RESERVOIR DAM, NEAR PERRÉGAUX, SHOWING WIDTH OF FLOOD PLAIN AND SMALL SIZE OF THE STREAM IN SUMMER.

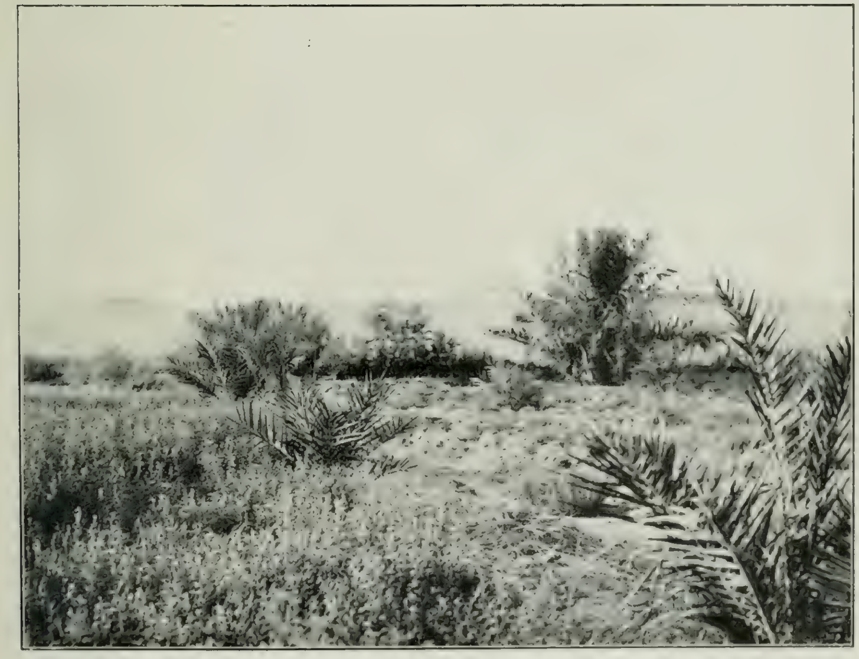

FIG. 2.—ALKALI-RESISTANT ALFALFA, NEAR TEMACIN, ALGERIAN SAHARA.

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